Journal

WATER POLLUTION CONTROL FEDERATION

FORMERLY SEWAGE AND INDUSTRIAL WASTES

Special Features

1959 Literature Review, Part III—Research Committee Water Pollution

Paper Chromatography—Buswell et al.

Sugar Waste—Keller and Huckabay

BOD Studies—Myrick and Busch

Red River Compact

Operator's Corner

Surface Coatings—Preparation, Application, and Inspection

JULY 1960

POSITIVE CONTROL OF *MATERIALS IN MOTION* B-I-F METERS FEEDERS CONTROLS

B-I-F *Builders-Providence* CHLORINIZERS . . .

SEE SAFETY IN ACTION!

See-Thru Components give Visual Proof of Operation . . . Positive Evidence of Effective Vacuum!

For extra safety in handling chlorine gas:

. . . full vision vacuum feed

. . . shortest flow path available

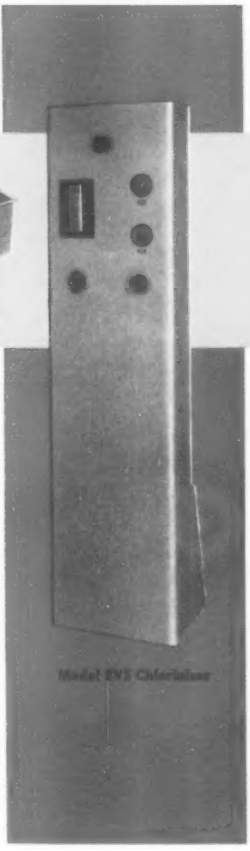
. . . automatic safety devices

. . . vital control and metering components not exposed to ravages of wet gas

Built-in safety reduces maintenance:

. . . gas doesn't contact water till *just prior* to entering injector . . . lowers maintenance, increases unit life and safety

. . . money-back performance guarantee



B-I-F *Industries*

BUILDERS-PROVIDENCE • PROPORTIONEERS • OMEGA

METERS • FEEDERS • CONTROLS / CONTINUOUS PROCESS ENGINEERING

For complete data:
request Bulletin 840-L23A, write

B-I-F Industries, Inc.
368 Harris Ave.
Providence 1, R. I.

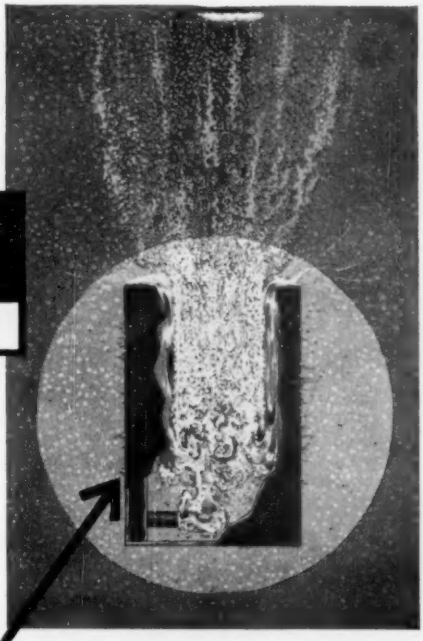
"from Chicago"

INTRODUCING

the Hydroshear

AIR DIFFUSION SYSTEM

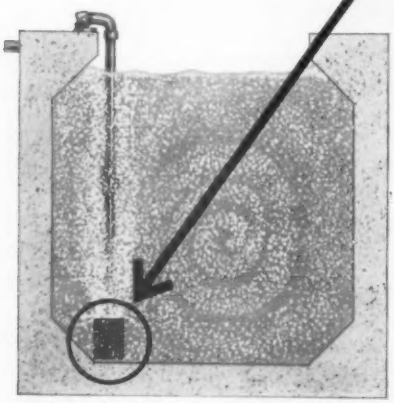
Patents Pending



HYDROSHEAR action in "SHEARFUSER" Nozzle Aerator

. . . induced counterflowing air-liquid streams shear large air globules from nozzles into fine bubbles . . . causing instantaneous oxygen transfer to liquid, from turbulence, and thousand-fold increased air film surfaces.

Fine bubbles from porous diffusers are recirculated by counterflowing streams to greatly increase total oxygen transfer due to sub-surface tank turbulence.



Aeration Tank section showing SWING DIFFUSER with "SHEARFUSER" Header

PROVIDES . . . CLOG-PROOF, highest oxygenation and circulation at lowest air pumpage and power usage.

USES . . . fine bubble "SHEARFUSER" Air Nozzles, or Porous Diffusers, to obtain required aeration . . . combined with SWING DIFFUSERS for operating flexibility.

Write for Bulletin 178

Putting Ideas to Work

FOOD MACHINERY AND CHEMICAL CORPORATION
HYDRODYNAMICS DIVISION

CHICAGO PUMP

622 DIVERSEY PARKWAY • CHICAGO 14, ILLINOIS

fmc
FOOD MACHINERY AND CHEMICAL CORPORATION

© 1960–CP–F. M. C.

JOURNAL of the WATER POLLUTION CONTROL FEDERATION

Volume 32 | **July 1960** | **Number 7**

Contents

1959 Literature Review

A Review of the Literature of 1959 on Wastewater and Water Pollution Control. By WPCF Research Committee.

Water Pollution 681

Sewage Works

A Paper Chromatographic Method for Volatile Acids. By A. M. Buswell, John R. Boring III, and James R. Milam 721

Flow Equations for Sewage Sludges. By Vaughn C. Behn 728

Industrial Wastes

The Selective Stimulation of Respiration in Mixed Cultures of Bacteria and Protozoa. By Nugent Myrick and A. W. Busch 741

Pollution Abatement in the Sugar Industry of Louisiana. By Arthur G. Keller and H. K. Huckabay 755

Stream Pollution

Water Quality Control Considerations in the Red River Compact.

I. Introduction. By Henry C. Beckman 761

II. Quality Degradation of the Red River by Natural Sources. By H. M. Crane 763

III. Quality Degradation of the Red River by Man-Made Sources. By D. F. Smallhorst 766

IV. One Abatement Program and Water Quality of the Ouachita River—A Tributary of the Red River. By G. T. Kellogg 768

V. The Downstream End. By John E. Trygg 770

VI. Water Quality Control in a Water-Rich State. By K. E. Biglane 772

The Operator's Corner

Surface Preparation. By Sheldon Dunning 775

Principal Protective Coatings for Wastewater Works. By Herman A. Knoedler.. 780

Inspecting Paint Coatings. By Sidney S. Lasswell 784

Impeller Repairs by Welding. By Leo Krapp 787

Tips and Quips 790

Editorial

Philadelphia in October 792

Annual Membership Contest Rules 793

Reviews and Abstracts 794

Proceedings of Member Associations

Pacific Northwest Sewage and Industrial Wastes Association 359a

New York Sewage and Industrial Wastes Association 363a

Equipment and Supplies 368a

Ralph E. Fuhrman, *Editor*, 4435 Wisconsin Ave., Washington 16, D. C.

Robert A. Canham, *Associate Editor* Robert A. Gerber, *Assistant Editor*

Philip A. Ridgely, *Production Manager*

Mailing Permit: Second class postage paid at Lancaster, Pa., and at additional mailing offices.

alert

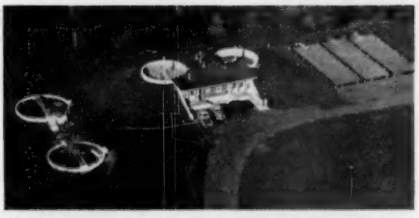
P. F. T. EQUIPMENT SERVING MILITARY ACADEMIES

ARMY

West Point, New York. Two 20' Floating Covers. One #170 Heater and Heat Exchanger Unit. Two Liquidometers and Floating Cover Position Indicators.

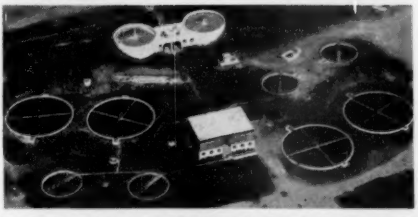
NAVY

Annapolis, Maryland. Two 25' Floating Covers. Two Supernatant Selectors and Supernatant Selector Gauges.



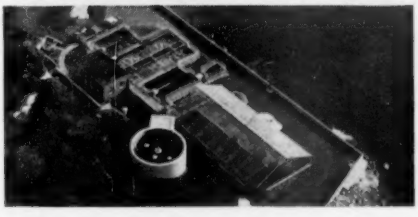
AIR FORCE

Colorado Springs, Colorado. Two 40' Floating Covers. One #250 Heater and Heat Exchanger Unit. Gas Safety Equipment.



COAST GUARD

Groton, Connecticut. One 28' Floating Cover. Gas Safety Equpiment.



P.F.T.

waste treatment equipment exclusively since 1893

PACIFIC FLUSH TANK CO.

4241 RAVENSWOOD AVENUE, CHICAGO 13, ILLINOIS

PORT CHESTER, N.Y. • SAN MATEO, CALIF. • CHARLOTTE, N.C. • JACKSONVILLE • DENVER

WATER POLLUTION CONTROL FEDERATION

PRESIDENT

MARK D. HOLLIS, Chief Engineer
U. S. Public Health Service
Washington 25, D. C.

VICE-PRESIDENT

RAY E. LAWRENCE
Black & Veatch
P. O. Box 8405
Kansas City 14, Missouri

TREASURER

A. H. NILES, Consultant
433 N.E. 33rd St.
Boca Raton, Florida

EXECUTIVE SECRETARY-EDITOR

RALPH E. FUHRMAN
4435 Wisconsin Ave.
Washington 16, D. C.

DIRECTORS

Ex-Officio: WILLIAM D. HATFIELD
Alabama: T. JAFFE (1960)
Arizona: E. O'NEAL DYE (1961)
Arkansas: M. L. WOOD (1961)
California: H. HARVEY HUNT (1961); R. D. BARGMAN (1962)
Canada: C. G. RUSSELL ARMSTRONG (1961)
Central States: M. S. NICHOLS (1960); E. J. BEATTY (1962)
Federal: G. E. MCCALLUM (1962)
Florida: D. B. SMITH (1962)
Georgia: M. B. NIXON (1962)
Germany: WILHELM HUSMANN (1962)
Indiana: W. W. MATHEWS (1961)
Inst. Sew. Pur. (Eng.): W. F. A. SNOOK (1962)
Inst. of Pub. Hlth. Eng. (Eng.): J. M. L. BOGLE
Iowa: H. S. SMITH (1962)
Israel: HILLEL SHUVAL (1960)
Kansas: CARL F. HODGKINSON (1960)
Kentucky-Tennessee: M. A. CHURCHILL (1961)
Louisiana: H. J. SCIONEAUX (1961)
Maryland-Delaware: H. A. SCHREIBER (1960)
Michigan: GEORGE E. HUBBELL (1961)
Mississippi: G. M. LESTER (1960)
Missouri: S. C. SMITH (1960)
Montana: (Election Pending)
Nebraska: T. A. FILIPI (1961)
New England: T. R. CAMP (1960)
New Jersey: R. S. SHAW (1960)
New York: C. E. IRVING (1960); G. A. FLEET (1962)
New Zealand: P. R. PARR (1962)
North Carolina: LEE S. DUKES, JR. (1961)
North Dakota: NORMAN PETERSON (1962)
Ohio: H. S. KLINE (1960)
Oklahoma: L. L. SETTLE (1962)
Pacific Northwest: R. T. SMITH (1962)
Pennsylvania: T. R. HASELTINE (1960); H. W. MCELHANEY (1961)
Puerto Rico: G. FLAQUES-GARCES (1962)
Rocky Mountain: J. H. MAGUIRE (1960)
South Carolina: J. D. LESSLIE (1961)
South Dakota: DON C. KALDA (1961)
Sweden: V. JANSA (1962)
Switzerland: ARNOLD HORLER (1960)
Texas: A. C. BRYAN (1960)
Utah: L. M. THATCHER (1960)
Virginia: E. H. RUEHL (1962)
West Virginia: P. T. ARBUCKLE (1962)
At Large: JACK MCKEE (1960)
At Large: CLAIR N. SAWYER (1961)
At Large: A. J. STEFFEN (1962)
W. and S. Wks. Mfrs.: G. E. HAUER (1960)
W. and S. Wks. Mfrs.: HARRY E. SCHLENZ (1961)
W. and S. Wks. Mfrs.: W. A. DARBY (1962)

JOURNAL of the WATER POLLUTION CONTROL FEDERATION®

A monthly journal devoted to the advancement of fundamental and practical knowledge concerning the nature, collection, treatment and disposal of sewage and industrial wastes, and the design, construction, operation and management of such works. The Journal was known as *Sewage Works Journal* until January 1950; thereupon it became *Sewage and Industrial Wastes* until January 1960, when it assumed its present name.

EDITORIAL AND EXECUTIVE OFFICES: 4435 Wisconsin Ave., N.W., Washington 16, D. C. Send all manuscripts, advertising copy, subscriptions, address changes, etc., to this address. JOURNAL WPCF is published monthly by the Water Pollution Control Federation at Prince & Lemon Sts., Lancaster, Pa.

SUBSCRIPTION RATES: Members of local associations affiliated with the Federation, $8.00 per year. Nonmembers, U. S. and Canada: $10.00; other countries, $11.50. (Foreign subscriptions must be accompanied by International Money Order.) Single copies: United States, $1.25 each; Foreign, $1.50 each.

CLAIMS: No claims will be allowed for copies of Journals lost in the mails unless such claims are received within sixty (60) days of the date of issue and no claims will be allowed for issues lost as a result of insufficient notice of change of address. "Missing from files" cannot be accepted as the reason for honoring a claim.

REFERENCE SERVICE: JOURNAL of the WATER POLLUTION CONTROL FEDERATION is indexed regularly by *Industrial Arts Index* and *Engineering Index*. Microfilm copies of this JOURNAL may be procured from University Microfilms, Ann Arbor, Mich. This service is limited to regular subscribers only.

Library of Congress Catalog Card Number: 42-19992.

Copyright © 1960, by the Water Pollution Control Federation. Reprints from this publication may be made only if permission of the Editor is secured and on condition that the full title of the article, name of the author and complete reference are given. The Federation assumes no responsibility for opinions or statements of facts expressed in papers or discussions published in this JOURNAL.

NICHOLS "ROTO-PLUG" CUTS INITIAL INSTALLATION COSTS 38%

The Nichols "Roto-Plug" Sludge Concentrator with its low initial installation cost—plus its inherent efficient and economical operation—places mechanical sludge dewatering within the reach of even the smallest community.

The "Roto-Plug" eliminates expensive vacuum and filtrate equipment, chemical mixing and feeding equipment, conditioning equipment, and high filter-media maintenance. Cost-wise this is a savings of 38% of the initial capital investment, compared with other methods of sludge dewatering.

Get all the facts about the economy of the "Roto-Plug". Write today for our four-page, two-color technical bulletin RP-100.

NICHOLS ENGINEERING & RESEARCH CORP.

80 Pine Street, New York 5, New York
3513 N. Hovey Street, Indianapolis 18, Ind.
405 Montgomery Street, San Francisco, Calif.

WPCF MEMBER ASSOCIATIONS

Alabama Water and Sewage Assn.*
E. J. FINNELL, JR., *Act.-Sec.*, Univ. of Alabama, University, Ala.

Arizona Sewage and Water Works Assn.*
A. D. COX, *Sec.-Treas.*, 2612 N. 16th St., Phoenix, Ariz.

Arkansas Water and Sewage Conf.*
DR. C. W. OXFORD, *Sec.-Treas.*, College of Engineering, University of Arkansas, Fayetteville, Ark.

California Sewage and Industrial Wastes Assn.
ROBERT L. WHITE, *Sec.-Treas.*, Bureau of Engr., City Hall, Burbank, Calif.

Canadian Institute on Sewage and Sanitation
DR. A. E. BERRY, *Sec.-Treas.*, Administrative Office, 72 Grenville St., Toronto, Ont., Canada

Central States Sewage and Industrial Wastes Assn.
SCOTT E. LINSLEY, *Sec.-Treas.*, 2400 Childs Rd., St. Paul 6, Minn.

Federal Sewage Research Assn.
RALPH HOLTJE, *Sec.-Treas.*, Public Health Service, Rm. 4123, South HEW Bldg., Washington 25, D. C.

Florida Sewage and Industrial Wastes Assn.
ARTHUR R. FINNEY, JR., *Sec.-Treas.*, 4801 S. W. 117th Ave., Miami 55, Fla.

Georgia Water and Sewage Assn.*
ROBERT S. INGOLS, *Sec.-Treas.*, Prof. of Applied Biology, Georgia Institute of Tech., Atlanta, Ga.

(Germany) Abwassertechnische Vereinigung
OTTO PALLASCH, *Sec.-Treas.*, Bertha-von-Suttner-Platz 8, Bonn, Germany

Indiana Sewage and Industrial Wastes Assn.
VICTOR G. WAGNER, *Sec.-Treas.*, St. Dept. of Hlth., 1330 W. Michigan St., Indianapolis 7, Ind.

Institute of Sewage Purification
W. F. A. SNOOK, *Sec.*, 10, Cromwell Place, South Kensington, London, S. W. 7, England

Institution of Public Health Engineers
ERNEST V. BALSOM, *Sec.*, 179 Vauxhall Bridge Road, London, S. W. 1, England

Iowa Sewage and Industrial Wastes Assn.
L. F. SKORCZESKI, *Sec.*, 207 South 15th Ave., Marshalltown, Iowa

Israel Assn. of Sewage Engineers
ELIEZER BALASHA, *Sec.*, c/o Technion, Israel Inst. of Tech., P. O. Box 4910, Haifa, Israel

Kansas Water Pollution Control Assn.
HOWARD F. SAIGER, *Sec.-Treas.*, 1900 East Ninth, Wichita, Kans.

Kentucky-Tennessee Industrial Wastes and Sewage Works Assn.
S. LEARY JONES, *Sec.-Treas.*, 602 Cordell Hull Bldg., Nashville 3, Tenn.

Louisiana Conference on Water Supply and Sewerage*
GEORGE H. WEST, *Sec.-Treas.*, P. O. Box 895, Water Dept., Lake Charles, La.

Maryland-Delaware Water and Sewage Assn.*
W. M. BINGLEY, *Sec.-Treas.*, c/o State Dept. of Health, 301 W. Preston St., Baltimore 1, Md.

Michigan Sewage and Industrial Wastes Assn.
D. M. PIERCE, *Sec.-Treas.*, Michigan Dept. of Health, Rm. 331, Admin. Bldg., Lansing 4, Mich.

Mississippi Sewage and Industrial Wastes Assn.
NEIL G. MCMAHON, *Sec.-Treas.*, Mississippi State Board of Health, Jackson, Miss.

Missouri Sewage and Industrial Wastes Assn.
JACK K. SMITH, *Sec.-Treas.*, Water Pollution Control Bd., 112 W. High, P.O. Box 154, Jefferson City, Mo.

Montana Sewage and Industrial Wastes Assn.
A. W. CLARKSON, *Sec.-Treas.*, Div. of Environ. Sanit., State Board of Health, Helena, Mont.

Nebraska Sewage and Industrial Wastes Assn.
E. BRUCE MEIER, *Sec.-Treas.*, Kirkham, Michael & Assoc., 508 S. 19th St., Omaha 2, Nebr.

New England Sewage and Industrial Wastes Assn.
EARL R. HOWARD, *Sec.-Treas.*, Bureau of Public Works, 115 Broad St., Hartford, Conn.

New Jersey Water Pollution Control Assn.
ANTHONY T. LEAHEY, *Sec.-Treas.*, P. O. Box 32, West Trenton, N. J.

New York Sewage and Industrial Wastes Assn.
RALPH C. SWEENEY, *Sec.*, c/o State Dept. of Health, 55 Church St., White Plains, N. Y.

New Zealand Sewage and Industrial Wastes Assn.
K. R. DAVIS, *Hon. Sec.-Treas.*, Auckland Metrop. Drain. Bd., P. O. Box 208, Auckland C. 1, New Zealand

North Carolina Sewage and Industrial Waste Assn.
T. Z. OSBORNE, *Sec.-Treas.*, Rm. 309 Municipal Bldg., Greensboro, N. C.

North Dakota Water and Sewage Works Conf.*
W. VAN HEUVELEN, *Sec.-Treas.*, State Dept. of Health, Bismarck, N. Dak.

Ohio Sewage and Industrial Wastes Treatment Conf.
E. B. RANSOM, *Sec.-Treas.*, Div. of San. Engr., Dept. of Hlth., 101 N. High St., Columbus 15, O.

Oklahoma Water, Sewage and Industrial Wastes Conf.*
H. M. CRANE, *Sec.-Treas.*, 3400 Northeastern, Oklahoma City 5, Okla.

Pacific Northwest Pollution Control Assn.
GILBERT H. DUNSTAN, *Sec.-Treas.*, P. O. Box 176, Pullman, Wash.

Pennsylvania Sewage and Industrial Wastes Assn.
J. R. HARVEY, *Sec.-Treas.*, c/o Pennsylvania Dept. of Health, 996 So. Main St., Meadville, Pa.

Puerto Rico Water and Sewage Works Assn.
ROBERT J. AULD, *Sec.-Treas.*, Espana 2015, Ocean Park, Santurce, P. R.

Rocky Mountain Sewage and Industrial Wastes Assn.
VERNE E. PLATH, *Sec.-Treas.*, P. O. Box 149, Englewood, Colo.

South Carolina Water and Sewage Works Assn.*
ROBERT N. BOWEN, *Sec.-Treas.*, 417 Wade Hampton Bldg., Columbia, S. C.

South Dakota Water and Sewage Works Conf.*
DON C. KALDA, *Sec.-Treas.*, Div. of San. Engr., State Board of Health, Pierre, S. Dak.

(Sweden) Föreningen för Vattenhygien
ERIK JONSSON, *Sec.*, Box 5038, Stockholm 5, Sweden

(Switzerland) Verband Schweizerischer Abwasserfachleute
PIERRE WILDI, *Sec.*, Hegemmatt 28, Zurich 2/38, Switzerland

Texas Water and Sewage Works Assn.*
G. R. HERZIK, JR., *Sec.-Treas.*, Div. of San. Engr., State Dept. of Health, Austin, Tex.

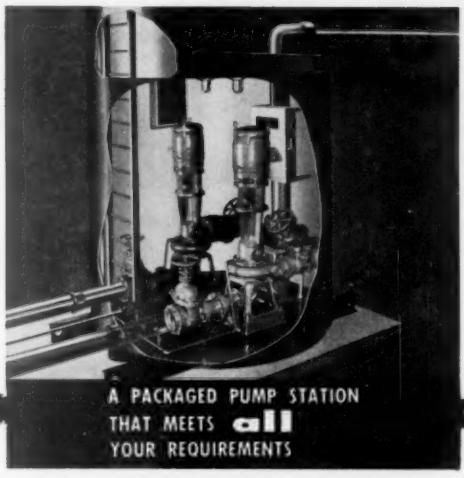
Utah Water Pollution Control Assn.
WILLIAM A. ANDERTON, *Sec.-Treas.*, 2500 S. State St., Salt Lake City 15, Utah

Virginia Industrial Wastes and Sewage Works Assn.
ORVAL J. HAND, *Sec.-Treas.*, Hercules Powder Co., Hopewell, Va.

West Virginia Water Pollution Control Assn.
GLEN O. FORTNEY, *Sec.-Treas.*, State Dept. of Health, Charleston 5, W. Va.

* Sewage and Industrial Wastes Section.

NOW... FROM TEX-VIT



- **ADVANCED DESIGN FOR GREATER EFFICIENCY**
  Compare motor and pump assembly of this duplex sewage pump station with any other and see the TEX-VIT superiority. Individual shaft for each pump and each motor. Four bearings per assembly instead of the customary two. Heavy steel shell, completely protected from corrosion.
- **DIRECT PRESSURE CONTROLS FOR EXTRA RELIABILITY**
  Exclusive TEX-VIT controls are actuated by pressure variations within the wet well. No compressor to maintain; no floats or other moving parts in the wet well.
- **IMPROVED AIR CIRCULATION AND CONDITIONING**
  Extra large blower provides complete change of air every 60 seconds. Air inlet and outlet are at opposite sides of station to prevent short circuiting of air. Refrigeration-type dehumidifier.
- **SUPERIOR COMPONENTS FOR EXTRA DEPENDABILITY**
  Pumps, motors, controls, and other components bear the brand names you would expect to find in a *Who's Who of American Industry*. You know you are getting the best when you specify TEX-VIT.
- **INSTALLATION TESTED AND PROVED**
  TEX-VIT packaged pump stations are setting new standards. Names of muncipal and industrial users furnished on request.
  Let TEX-VIT help you with your sewage lift problems. TEX-VIT also makes pneumatic ejectors and packaged ejector stations.

Write for bulletin No. PS-60

TEX-VIT
SUPPLY COMPANY
MANUFACTURING DIVISION
Dept. S-7, Box 117, Mineral Wells, Texas

MEMBER ASSOCIATION MEETINGS

Association *	*Date*	*Place*
ISP (England)	June 21–24	Scarborough, England
Pennsylvania	Aug. 10–12	Pa. State Univ., University Park
Georgia	Sept. 7–9	Georgia Inst. of Tech., Atlanta
South Dakota	Sept. 7–9	Grand Hotel, Watertown
Kentucky-Tennessee	Sept. 12–14	Andrew Jackson Hotel, Knoxville, Tenn.
Missouri	Sept. 25–27	Hotel Governor, Jefferson City
North Dakota	Oct. 5–7	Grand Pacific Hotel, Bismarck
Pacific Northwest	Oct. 20–22	Marcus Whitman Hotel, Walla Walla, Wash.
Rocky Mountain	Oct. 24–26	Broadmoor Hotel, Colorado Springs, Colo.
Canada	Oct. 24–27	Statler Hotel, Buffalo, N. Y.
New England	Oct. 26–27	Taft Hotel, New Haven, Conn.
Nebraska	Nov. 3–4	Castle Hotel, Omaha
South Carolina	Nov. 4	Jefferson Hotel, Columbia
North Carolina	Nov. 9–11	R. E. Lee Hotel, Winston-Salem
Florida	Nov. 13–16	Galt Ocean Mile Hotel, Fort Lauderdale
Oklahoma	Nov. 14–18	State University, Stillwater
Indiana	Nov. 16–17	Hotel Washington, Indianapolis

* See preceding left-hand page for full name.

THIRTY-THIRD ANNUAL MEETING

Water Pollution Control Federation

Host—Pennsylvania Sewage and Industrial Wastes Association
Philadelphia, Pennsylvania

Technical Meetings and Exhibits—Convention Hall
Hotel Headquarters—Sheraton
October 2–6, 1960

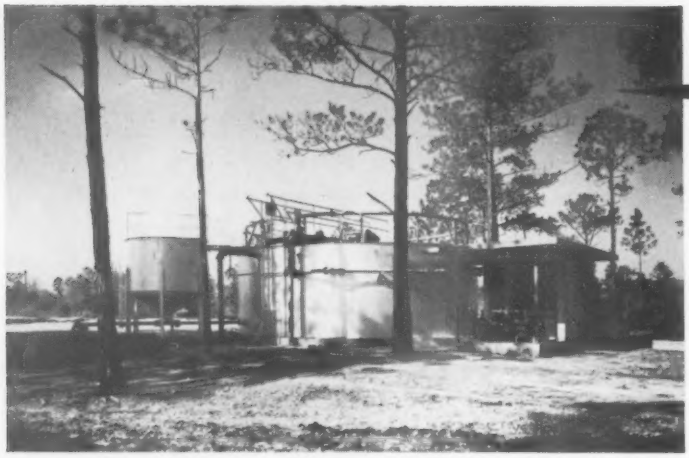
NEW MANUAL AVAILABLE

M. O. P. 7—SEWER MAINTENANCE

- complete coverage for protecting a $15 billion investment
- a *first* in the field
- 64 pages
- 68 references
- $1.00 to members; $1.50 to others
- see coupon on p. 361a

WATER POLLUTION CONTROL FEDERATION

4435 Wisconsin Avenue Washington 16, D.C.



Low-cost treatment for small sewage flows . . .

Aerobic Digestion

— an extended activated sludge process in which essentially all volatile influent solids are oxidized by the continued recirculation and re-aeration of raw sewage and highly concentrated return sludge.

Two types of Eimco-Process single tank Aerobic Digestion plants now provide low-cost, high-degree purification for sewage flows of 1,000 to 15,000 GPD . . . and for flows 15,000 to 300,000 GPD.

Both types achieve 85 to 95% suspended solids and BOD reductions in approximately 24 hours aeration and 4 hours settling time. Solids are reduced to a stable ash. Effluent is clear and odorless.

Eimco-Process plants for aerobic digestion are complete treatment plants, requiring a minimum investment in equipment. No primary settling tank and no separate tanks for digestion, clarification or storage are required. No sludge drying beds are needed. Maintenance consists only of routine lubrication and periodic housekeeping.

In the smaller sizes, Eimco-Process plants are prefabricated for truck shipment; larger size units are designed for minimum field fabrication. Aerobic digestion plants arrive with all auxiliaries, and equipped with Non-Clog Diffusers, an Eimco-Process development for aeration that eliminates clogging and the need for backflushing.

Eimco-Process Aerobic Digestion plants have also been successfully applied for many types of miscellaneous wastes. The Eimco representative in your area can be most helpful to you or to your consulting engineers in determining the type and size aerobic digestion plant most economical for your needs.

Type ADC

for flows over 15,000 GPD

Circular tank units with aeration compartment surrounding settling and clarification tank. Equipped with motor-driven sludge removal mechanism, blower, and skimmer arm. 14 *sizes.*

Type ADR

for flows 1,000 to 15,000 GPD

Rectangular steel tank design with baffle separating aeration from settling and clarification compartments. Settled sludge is returned to aeration compartment continuously. 8 *sizes.*

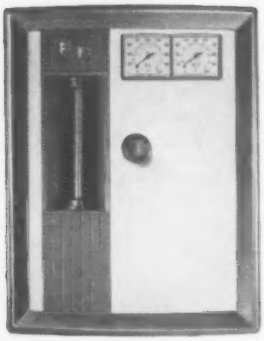
THE EIMCO CORPORATION

Process Engineers Division

420 Peninsular Avenue
San Mateo, California B-623

NEW BULLETIN ON AEROBIC DIGESTION

Write Eimco's Process Engineers Division for your copy, or ask the Eimco representative nearest you for BULLETIN SM-1010.



This, believe it or not, is a wall mounted chlorinator. Its attractive appearance is our way of showing how proud we are of the advanced operating parts hidden behind the front panel. For example: This is the first wall mounted chlorinator ever to feature a single stack regulator. Simple, compact appearance belies the fact that it can handle up to 200 pounds per day of chlorine more accurately, dependably, and safely than any other chlorinator with the single exception of its big brothers. It is so completely corrosion-proof in the right places that we have little hope of ever selling replacement units. In short, we have never been happier with any product than we are with the new Series 3600 chlorinators .

Should you wish to order one of these beauties sight-unseen, on our say-so, we can deliver immediately from warehouse stocks across the country. If not, your local F&P field office will gladly demonstrate the 3600 Series at your plant, at your convenience. Call for an appointment. Or, write for complete information in Bulletin 70C3600. Fischer & Porter Company, 1170 Fischer Road, Warminster, Pa.

FP

FISCHER & PORTER COMPANY

INSTRUMENTATION AND CHLORINATION

These MANUFACTURING AFFILIATES carry Fischer & Porter engineering designs to the far corners of the earth: FISCHER & PORTER (CANADA) LTD., DOWNSVIEW, ONTARIO • FISCHER & PORTER LTD., WORKINGTON, CUMBERLAND, ENGLAND • FISCHER & PORTER G.m.b.H., GROSSELLERSHAUSEN, BEI GOTTINGEN, GERMANY • FISCHER & PORTER N.V., KOMEETWEG 11, THE HAGUE, NETHERLANDS • FISCHER & PORTER Pty. LTD., 184 HANNA ST., SOUTH MELBOURNE, VICTORIA, AUSTRALIA.

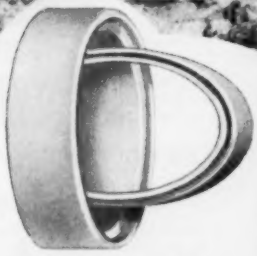
PRECAST CONCRETE SEWER ELEMENTS

for lasting service at low cost

American-Marietta offers concrete manholes and a variety of pipe styles—each precast for faster installation at less cost—each designed to do a specific job better. A-M Concrete Products plants are strategically located throughout the country to assure quick delivery. Write for the name of the plant nearest you and ask for free literature on any of the products illustrated below.

HI-HED® PIPE

Saves trench width in congested areas



INNER CIRCLES®

Minimizes surface excavations, makes salvaging of old sewers easier

LO-HED® PIPE

Minimum depth of cut—affords increased cushion of cover

CONCRETE PIPE

Strengths pretested to eliminate guesswork

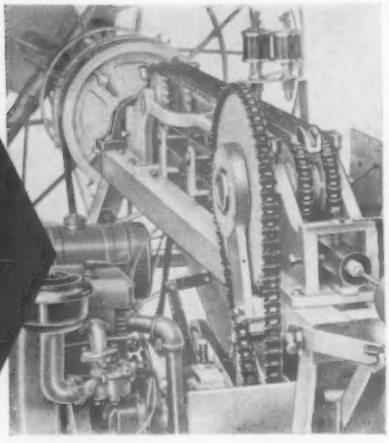
AMERICAN-MARIETTA COMPANY

CONCRETE PRODUCTS DIVISION

GENERAL OFFICES:
AMERICAN-MARIETTA BUILDING
101 EAST ONTARIO STREET, CHICAGO 11, ILLINOIS, PHONE: WHITEHALL 4-5600

FOR SEWER CLEANING

Positive NON-SLIP Rod Drive



The HEART of the Flexible "Automatic" SEWERODER

- Hardened Steel Drive Dogs, spaced between endless dual chains, provide controlled, non-slip power up to 4,000 lbs., no matter how greasy or muddy the rods may be.
- The Safety Overload Clutch protects pipe, rods, machine. Easily adjustable to relieve on predetermined overloads.
- The Footage Meter is synchronized with rod drive for pin-point tool location. Its accuracy eliminates costly guesswork in locating broken pipe.

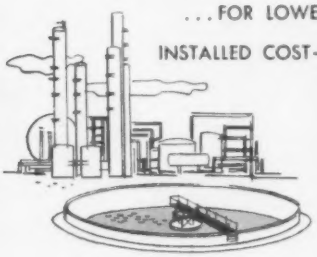
Your "Flexible" representative will be glad to give you facts and figures or write for the SEWERODER Brochure.

FLEXIBLE INC.

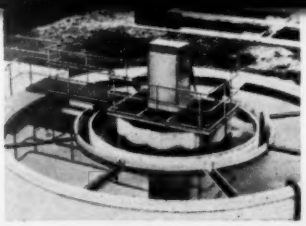
3786 DURANGO AVE., LOS ANGELES 34, CALIF.
1005 SPENCERVILLE ROAD, LIMA, OHIO
415 SOUTH ZANGS BLVD., DALLAS, TEXAS

IN THE MINIMUM SPACE

. . . FOR LOWER INSTALLED COST—



. . . YOU get *highest* performance and *greatest* economy with INFILCO waste treatment equipment



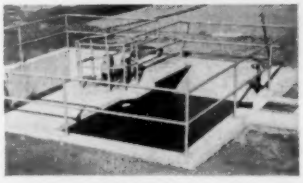
AERO-ACCELATOR
(TRADE MARK)

activated sludge plant. Compact and efficient.

A high-rate, multi-purpose unit for rapid, continuous biological oxidation and clarification; efficient and stable operation at high loads. BULLETIN 6510

CYCLATOR® clarifier

. . . for effective treatment of industrial waste waters where the concentration and dewatering of voluminous sludges are involved. Clarification by chemical and mechanical methods with solids recirculation in a single compact unit. Three types of surface skimmers available for different applications. BULLETIN 850



VORTI® Mixers

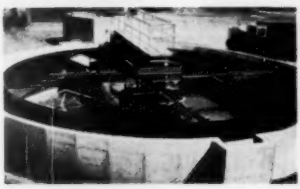
Efficient vortex flow pattern, reduced power consumption.

Provide turbulent agitation by controlled multi-directional circulation. For round, square or rectangular equalization, reaction or flocculation basins. Simple, trouble-free design; no underwater bearings. BULLETIN 700

CLARIFIER-THICKENERS

For simple clarification or thickening by sedimentation.

Type WS for small diameters, Types BF or PDR for large diameters. Three types of surface skimmers available for different applications. Special designs for sludge thickening. BULLETIN 800/6000



SEDIFLOTOR®

clarifiers enable both sedimentation and flotation in one compact unit

Where space is limited and clarification a must, this air flotation unit is ideal for removal of both flotable materials and settleable solids. BULLETIN 6051

CHEMICAL FEEDERS

Full variety with many exclusive features available.

Lime slakers, dry, solution and slurry-feed types, available for either constant or variable-rate operation.

REQUEST INFORMATION

INFILCO
INCORPORATED
General Offices • Tucson, Arizona • P.O. Box 5033
Field offices throughout the United States and in foreign countries

57443-A

INFILCO KNOWS HOW to help you control pollution, water reclamation and materials loss problems.

No other line of waste treatment equipment is so complete as INFILCO's—none so advanced in method and design. There are many other units in addition to typical examples illustrated above.

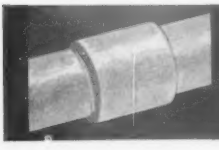
INFILCO engineers know how to help solve your waste-water disposal problems with knowledge gained from many years of specialized experience in industrial waste treatment. Write today for bulletins of interest to you. Inquiries are invited on all waste-water treatment problems.

INFILCO

THE ONLY COMPANY impartially offering equipment for ALL types of water and waste processing—coagulation, precipitation, sedimentation, flotation, filtration, ion exchange and biological treatment.

you don't need an "eye"

Keasbey & Matti



Exclusive, patented "K&M" FLUID-TITE Coupling forms a permanent leakproof seal.

Permanently smooth bore provides excellent flow characteristics.

out for trouble

after you install

"K&M"

ASBESTOS-CEMENT SEWER PIPE

"K&M" Asbestos-Cement Sewer Pipe helps you provide the best sewer service available . . . with tax savings that go on year after year.

This thrifty pipe is infiltration-proof, even when external water pressure is 25 psi. Prevents your sewer system from reaching full capacity years ahead of schedule, due to water infiltration. "K&M" Asbestos-Cement Sewer Pipe, with exclusive, patented FLUID-TITE Coupling, forms a permanently tight seal.

In planning your system, you can build on flatter grades with "K&M" Asbestos-Cement Sewer Pipe. Need fewer lift stations. The permanently smooth bore of "K&M" Asbestos-Cement Sewer Pipe has a Manning factor of n = 0.010. Flow characteristics are excellent. Inspections and treatment loads become less frequent.

This thriftiness carries over into installation. Neither weather nor soil conditions need hold up work. The "K&M" FLUID-TITE Coupling slides on in just two easy steps. Longer pipe lengths minimize the number of joints.

Write today for more detailed and illustrated information on hardy "K&M" Asbestos-Cement Sewer Pipe. Learn why thousands of progressive communities have turned to this durable quality pipe. Write to: Keasbey & Mattison Company, Ambler, Pa., Dept. P-550.

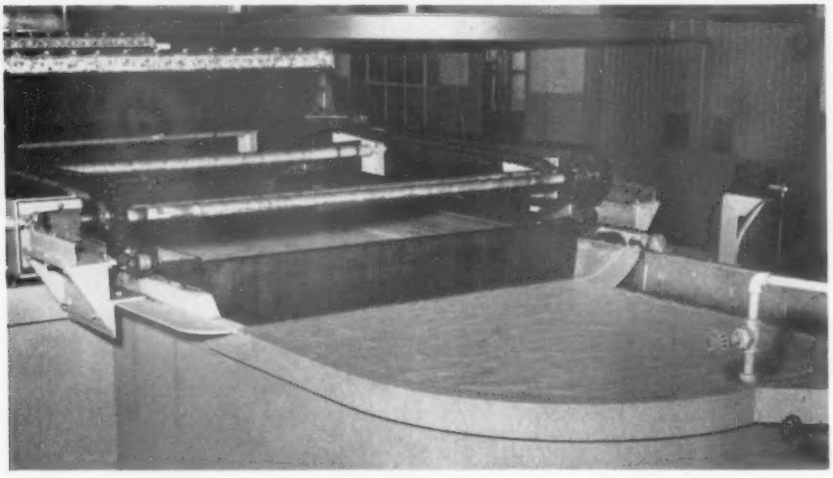
son at Ambler

K·M BEST IN ASBESTOS

Easy installation! Couplings join quickly. No heavyweight coupling pullers needed.

"K&M" PLASTIC SEWER PIPE complements "K&M" Asbestos-Cement Sewer Pipe in many sewer systems. Excellent flow characteristics and permanently tight joints. Write for Technical Bulletins on "K&M" High-Impact Styrene-Alloy Sewer Pipe. Dept. P-550.

FLUIDICS* AT WORK



How this company cuts oil to less than 10 ppm in waste waters

You're looking at waste water being treated at International Harvester's plant at Fort Wayne, Indiana.

This water holds soluble and insoluble oils, alkaline cleaner fluids, mineral acids, corrosive salts and other contaminants. The quantities of these compounds vary from hour to hour, so the waste is sometimes predominantly acidic, sometimes predominantly alkaline.

Yet the single piece of equipment you see here, plus its accessories, takes this waste water and treats it so thoroughly it can be safely pumped into an open stream. Oil, for example, is reduced to less than 10 ppm. If it were necessary, the oil could be reduced to less than 1 ppm by further treatment.

How it is done

The single unit that makes these results possible is the Permutit Colloidair Separator.

It uses a relatively low-cost "bubbling out" process to remove wastes.

Air is forced into solution with the waste waters, under pressure. The mixture is then released to atmospheric pressure, causing the air to form millions of tiny bubbles, which collect around the solids and lift them to the surface of the tank, where they can be skimmed off and dumped into a disposal pit.

The Colloidair Separator is effective for processing solutions containing clays, greases, fibers, oils, paints, fats and many other suspended solids.

If you would like to find out more about the economies and efficiency of the Permutit Colloidair system, send for a copy of our Bulletin 4511.

Permutit Division, Dept. JWP-70, 50 West 44th St., New York 36, N. Y.

*FLUIDICS is the Pfaudler Permutit program that integrates knowledge, equipment and experience in solving problems involving fluids.

PFAUDLER PERMUTIT INC.

Specialists in FLUIDICS...the science of fluid processes

Low-cost FIBRE PIPE forms 30" I.D. surge pond line

USE STRONG, CORROSION-PROOF

SONOCO
P.I.
PITCH-IMPREGNATED
PIPE

Here, corrosion resistant P.I. PIPE was used to form the effluent line for a surge pond . . . the first stage of a paper mill waste disposal system.

P.I. PIPE is a new SONOCO development—the *only* fibre pipe made in I.D's to 36 inches! Because it is impervious to the action of strong chemicals and requires no mastic coating or special treatment, P.I. PIPE is particularly valuable for industrial waste disposal systems. It combines this high corrosion resistance with great strength, light weight, and ease of installation . . . to provide an excellent pipe for industrial venting and all types of gravity flow lines where the maximum head does not exceed 20 feet.

Strong, tough P.I. PIPE is composed of many layers of quality fibre, tightly bonded together and impregnated with liquefied coal tar pitch. In any diameter you order, the thickness of the pipe wall can be varied to meet specified crushing strength requirements. This means a better, more economical installation.

Save labor, save replacements, save money . . . use low-cost Sonoco P.I. PIPE . . . newest development in fibre pipe!

P.I. PIPE comes in 10' lengths up to 36" I.D.; straight line fibre couplings available with or without neoprene gaskets. Can be sawed, or drilled and tapped for special fittings. Steel fittings may be connected to P.I. PIPE with Dresser or other similar couplings.

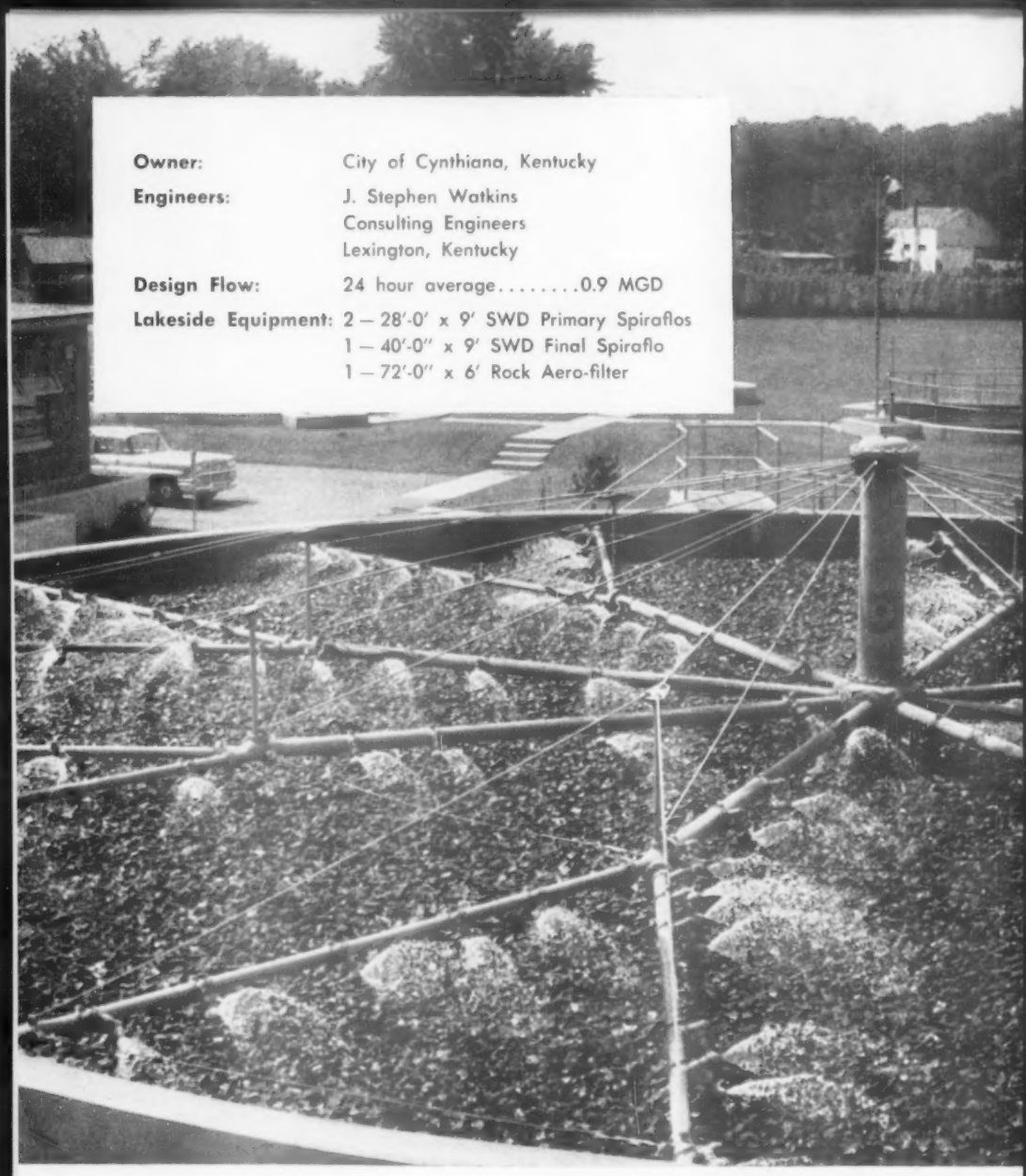
For complete information and prices, write

SONOCO

Construction Products

4668

SONOCO PRODUCTS COMPANY • HARTSVILLE, S. C.



Owner:	City of Cynthiana, Kentucky
Engineers:	J. Stephen Watkins Consulting Engineers Lexington, Kentucky
Design Flow:	24 hour average.....0.9 MGD
Lakeside Equipment:	2 — 28'-0' x 9' SWD Primary Spiraflos 1 — 40'-0" x 9' SWD Final Spiraflo 1 — 72'-0" x 6' Rock Aero-filter

AERO-FILTERS: The high rate filter with raindrop-like application. Proven results based on the biologically accepted facts that proper feeding of a trickling filter will result in a consistently higher BOD removal per cubic yard of filter media. Added advantages include . . . smaller diameter filter beds, less filter fly nuisance, higher hydraulic loadings, and lower recirculation ratios. Over 200 Aero-filters in operation. *Write for Bulletin #116.*

LAKESIDE

ENGINEERING CORPORATION

222 West Adams St., Chicago 6, Illinois

WHEN CITIES PLAN INDUSTRIAL GROWTH

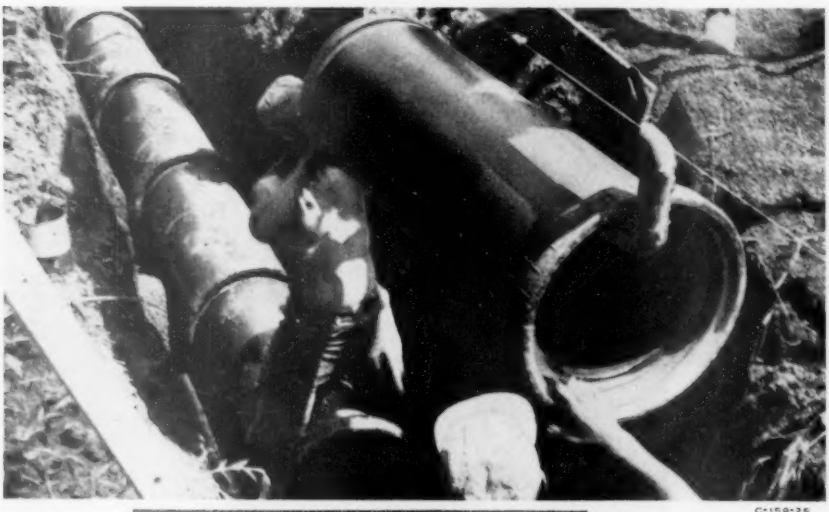
IT PAYS TO SPECIFY CLAY PIPE

SANTA PAULA, CALIFORNIA, already a bustling center of agricultural activity, is building to share in California's phenomenal industrial growth. To accommodate new industry and meet the needs of a growing population, Santa Paula recently completed a bond-financed sewer expansion project, using Vitrified Clay Pipe exclusively. Over 6 miles of Vitrified Clay Pipe were installed.

Like Santa Paula, growing communities everywhere need the permanence and safety that only Clay Pipe can provide. Clay Pipe is the only pipe that never wears out . . . does not rust, rot, corrode, or crumble. And with its new research-developed, factory-made joints, Clay Pipe is faster and easier to install than ever before.

When your community plans new sewerage facilities, be sure to consider the exceptional advantages of Clay Pipe. Its exclusive long-term guarantee is your assurance of permanent, maintenance-free service. Only Clay Pipe has *all* the features you can trust to handle industrial growth.

CITY OFFICIALS: James E. Leary, Mayor; Edwin C. Bixby, Ernest H. Oman, Ralph B. Crawford, Reece B. McCalister, Councilmen.
CONSULTING ENGINEERS: J. M. Montgomery Engineering Co. **CONTRACTOR:** N. P. Van Volkenburgh Co.



C-159-25

Vitrified **CLAY PIPE** *Never Wears Out*

NATIONAL CLAY PIPE MANUFACTURERS, INC.

1820 N St. N. W., Washington 6, D. C.

311 High Long Bldg., 5 E. Long St., Columbus 15, Ohio • 445 Ninth St., San Francisco 3, Calif.
Box 172, Barrington, Illinois • 1401 Peachtree St., N. E., Atlanta 3, Georgia

DON'T BE FOOLED BY INITIAL PIPE COSTS...

Certain factors concerning the type of pipe to be used for a proposed water or gas project must be examined carefully:

First — how much does the pipe cost, compared to other types?

Second — how often will it require repair?

Third — how long before it has to be replaced?

Sometimes the first cost of jobs where cast iron pipe is specified, is higher than similar projects using cheaper pipe. Yet, in the long run, cast iron pipe costs *less!* Here's why:

- Cast iron pipe rarely requires repairs. Its rugged construction, corrosion-resistant qualities and bottle-tight rubber-ring joints will withstand the most severe pressures.

- Cast iron pipe is built to *last*—98 American cities will testify to that. They've had cast iron pipe installations in constant use for over a century! Once cast iron pipe is in the ground, it stays there!

Don't be fooled by "low-cost" pipe. Insist on the pipe that will actually save you money over a period of years.

In Nebraska—Here a section of cast iron pipe is being relocated. Twenty-five years old, the pipe is still in excellent condition—has never required major repair . . . or replacement.

Rely on CAST IRON PIPE

In Indiana (above)—"All-weather" cast iron pipe is quickly installed despite wet trench conditions. Slip-on joints were easily assembled, with one workman using a crowbar.

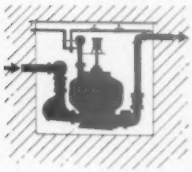
In Kansas (above)—36" cast iron water main. Another part of this main was floated out of its trench by a heavy downpour. Later a 150 psi water test revealed no leaks in the slip-on joints!

In Pennsylvania (below)—This 16" cast iron pipe is being installed as fast as the trench hoe can prepare the trench. Handy lengths and slip-on joints make cast iron pipe easy to handle, even in crowded neighborhood sectors; require less labor.

CAST IRON PIPE
THE MARK OF THE 100-YEAR PIPE
Cast Iron Pipe Research Association, Thos. F. Wolfe
Managing Director, 3440 Prudential Plaza, Chicago 1, Ill.

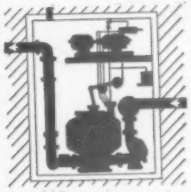
Which sewage lift station is best for your job?

TOPS IN DEPENDABILITY AND SAFETY



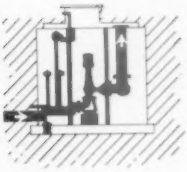
Concrete or steel underground station with Shone® Type S pneumatic ejector, mechanically controlled (warranted 25 years). Remote air supply. Nothing electrical; maintenance free; operates even under water. For municipalities and large subdivisions.

SUPRISINGLY VERSATILE, INEXPENSIVE



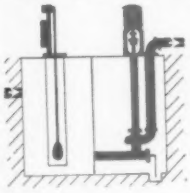
Shone® Type SAC station, underground in concrete vault. Mechanically controlled ejector (warranted 25 years) has its own compressor. Frequently less costly than package stations. Finds use everywhere.

PACKAGE STATION



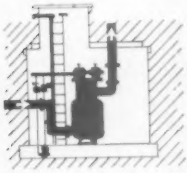
Quality underground station with vertical, short-coupled (Series 6260), dry pit centrifugal pumps. Quality design and equipment give good service life at nominal cost. For small permanent stations, growing areas.

LOW FIRST COST—EASY INSTALLATION



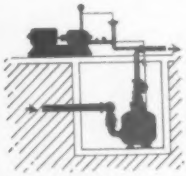
Two-compartment steel basin with centrifugal vertical wet pit pump. Pumps are not submerged; motors protected from flooding. Low first cost; fast installation. For buildings, small growing subdivisions.

ULTIMATE IN PACKAGE DESIGN



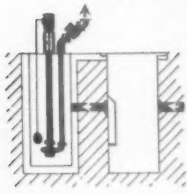
Package underground station with Expelsor® pneumatic ejector, electrode controlled. Sanitary and dependable, low maintenance, easy to service. Recommended for municipal and subdivision applications.

BUILDING TYPE STATION



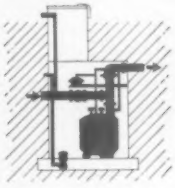
Expelsor® pneumatic ejector station designed for use in buildings. Compressor is on basement floor; ejector on floor below. Sealed installation gives safe, odorless handling of sewage indoors.

SPECIAL PROBLEMS?



Centrifugal vertical wet pit pumps with adjoining settling basin. Good for areas where sand or old sewers create problems. Special pump construction for abrasive or corrosive conditions, industrial wastes.

MAXIMUM RELIABILITY—MINIMUM SPACE



Package underground station. Expelsor® pneumatic ejector has two compartments, duplex compressors and controls. Excellent service accessibility. Especially suited for subdivision and municipal lift stations.

The answer depends on the job. Is it to be a temporary station? What about future loads? How much maintenance will it get? What type of power is available? These and many other questions must be weighed carefully and without bias. In making the decision, why not put Yeomans 61 years' experience (59 on underground stations alone) to work? Because Yeomans builds *the only complete line* of sewage lift stations in the industry, recommendations are *impartial* and in your best interest. Phone, wire, or write now.

L-5911

YEOMANS

1999-7 N. Ruby St., Melrose Park, Ill.

SPECIALISTS IN SEWAGE LIFT STATIONS—THE COMPLETE LINE

You can thank Johns-Manville's patented Ring-Tite® Joint which cuts ground water infiltration to a minimum. It's exclusive on *Transite®, the white sewer pipe.*

On a recent sewer project, specifications called for an extremely exacting infiltration test. What was the outcome? At final inspection, infiltration in the Transite line was 80% *less* than specification. What does this mean? Important savings! Volume of sewage to be treated is kept to a minimum . . . treatment plant operates as designed. The plant's reserve is conserved for future service.

Transite, made of tough, durable asbestos and cement, with its tight joints, offers many other savings. The long, light-weight lengths and sure coupling methods reduce trenching and installation costs. Transite's low coefficient of friction means faster flow and shallower trenches. Preventive maintenance with Transite will save you thousands of dollars.

Take it from Hartley—Transite can provide important economies in all sewer projects. Get all the details on Transite, the white sewer pipe. Send for your facts and data book today! Write Johns-Manville, Box 14, JW-7, New York 16, N. Y. In Canada: Port Credit, Ontario.

JOHNS-MANVILLE
TRANSITE PIPE

JM

Rodney Hunt gates of tough Everdur withstand bleach-plant acid and pulp-mill wastes

Settling tanks of one of the first industrial waste-treatment plants in the paper industry at the Covington, Va., plant of West Virginia Pulp and Paper Co. Everdur was specified for mixing-chamber gates to resist corrosion by bleach-plant acids and pulp-mill wastes.

One of a pair of mixing-chamber gates fabricated of Everdur, each 48" wide by 54" high. The slide is a sheet of Everdur, reinforced by Everdur angles braze-welded in place. Frame and 2" stem also of Everdur.

Resists corrosion. Sewage treatment and waterworks equipment of Everdur* has been in service without replacement for 20 years and longer.

Toughness. Everdur also possesses high strength and resistance to wear and abrasion —so that engineers can use lighter weight wrought material in their designs.

Readily fabricated. Alloys of Everdur are available for hot or cold working, welding, free machining, forging and casting — and can be obtained in plates, sheets, rods, bars, angles, channels, tees, I-beams, wire, tubes, electrical conduit and casting ingots.

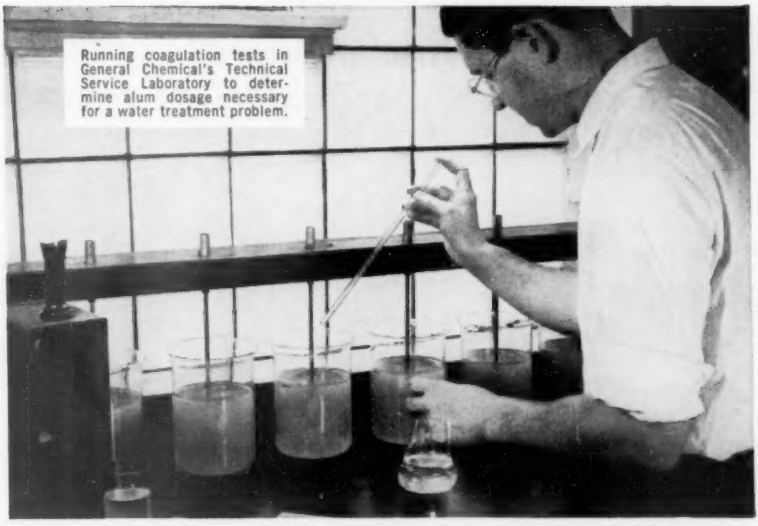
Write for Publication E-11, "Everdur Copper-Silicon Alloys for Sewage Treatment and Waterworks Equipment" — or for technical help in selecting the correct material for your job. Address: The American Brass Company, Waterbury 20, Conn. In Canada: Anaconda American Brass Limited, New Toronto, Ont.

*Reg. U. S. Pat. Off. 57131

EVERDUR Anaconda's family of Copper-Silicon Alloys

MADE BY THE AMERICAN BRASS COMPANY

STRONG · WORKABLE · WELDABLE · CORROSION-RESISTANT



Running coagulation tests in General Chemical's Technical Service Laboratory to determine alum dosage necessary for a water treatment problem.

Another difference in GENERAL CHEMICAL ALUM is TECHNICAL SERVICE

As the country's primary producer of aluminum sulfate, General Chemical constantly helps customers solve technical problems involving the use of alum. Results? Improved efficiency and reduced operating costs for them. Here are some of the services our Technical Service Department offers:

- Supplying basic information helpful in planning design and installation of storing, pumping, metering and feeding facilities.
- Suggesting improvements to eliminate existing storing and handling problems.
- Providing chemists and operators with physical and chemical data necessary for the most effective use of alum.
- Assisting in laboratory tests and plant trials.
- Running check analyses in our own laboratories.

In water and sewage plants, our specialists provide valuable help and guidance on storage, handling and feeding problems, as well as the important conversion from dry to liquid alum. They can help plant operators establish the best alum dosage. They recommend coagulation aids to improve flocculation in difficult water or waste treatment conditions.

This kind of Technical Service is one of the reasons why General Chemical is a good company to do business with for *your* plant's aluminum sulfate requirements. We will welcome the opportunity to serve you.

Basic to America's Progress

Allied Chemical

GENERAL CHEMICAL DIVISION
40 Rector Street, New York 6, N. Y.

Attractive, Corrosion-Resistant Glazed-Tile
Effluent and Water Treatment Tanks

Exacting Design —
Meticulous Workmanship

As the final step of construction, Stebbins workmen carefully wash down the exterior of the tanks with acid.

In this view of tank floors under construction, note the clean, smooth joints – the mark of good workmanship. Note the variety of tile shapes. Horizontal and vertical steel reinforcing is shown in the walls which will be solidly filled with concrete as work progresses.

Complete Service —
Design, Installation, Maintenance

WRITE FOR BULLETIN AET-59

SEMCO

STEBBINS Engineering and Manufacturing Company

WATERTOWN, N. Y. • PENSACOLA, FLORIDA

STEBBINS ENGINEERING CORP. — 2611 MARKET ST., SEATTLE 7, WASH.

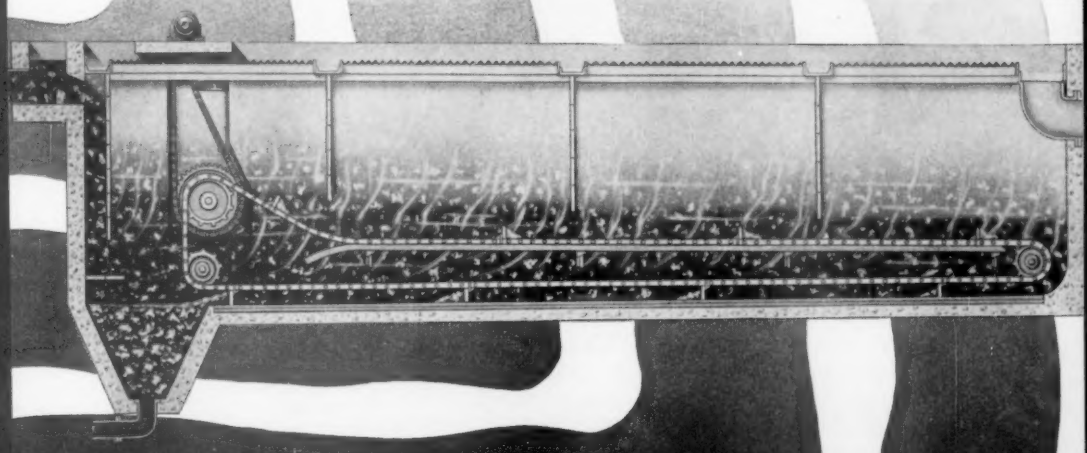
CANADIAN STEBBINS ENGINEERING & MANUFACTURING CO., LTD.

TOWN OF MOUNT ROYAL, MONTREAL 9 • MERCHANT EXCHANGE BLDG., VANCOUVER

SINCE 1884

Specialists in Design, Installation and Servicing of Linings and Tile Tanks

we DIVIDE to MULTIPLY



we DIVIDE the flow to MULTIPLY clarifier capacity

Rex Verti-Flo not only increases the clarifying capacity of tanks up to four times; it provides a far clearer effluent. The savings in equipment and construction costs are obvious. Here's how Verti-Flo does it: The unique design of Rex Verti-Flo Clarifier transforms the conventional horizontal-flow tank into a vertical-flow tank...utilizing the *full volume* of the tank and *minimizing short-circuiting*. This is accomplished by a system of collecting troughs, weirs and partitioning baffles which divide the large, horizontal settling zone into a series of small, vertical-flow cells. To assure maximum flow length and control, the weirs are adjustable entirely around the periphery of each cell.

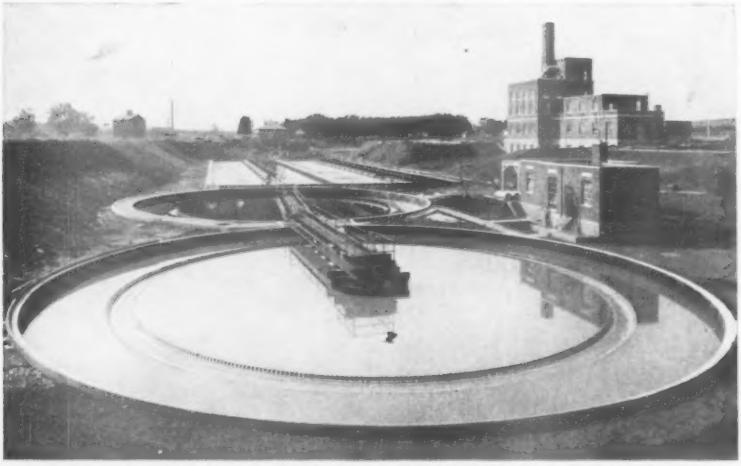
Installed in existing tanks, Verti-Flo can be at least double the capacity of the tank...in new installations, Verti-Flo provides up to four times more capacity so that smaller basins can be used with considerable savings in both equipment and construction costs.

For information, write CHAIN Belt Company, 4606 W. Greenfield Ave., Milwaukee 1, Wis.

REX®

CHAIN BELT COMPANY

for circular or rectangular tanks...



Hardinge can handle your sewage or waste clarifying problems whether your design calls for circular clarifiers as shown above (on final sewage clarification) or . . .

rectangular construction, as shown here (on primary sewage clarification). Sludge thickeners and digesters are also offered by Hardinge. (Bulletin 35-D-16)

HARDINGE

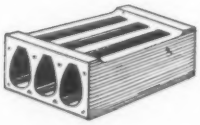
COMPANY, INCORPORATED

Main Office and Works • 240 Arch St., York, Pa.

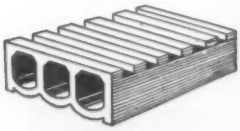
"Hardinge Equipment—Built Better to Last Longer."

NEW YORK
TORONTO
CHICAGO
HIBBING
SALT LAKE CITY
SAN FRANCISCO
HOUSTON
LAKELAND
BIRMINGHAM

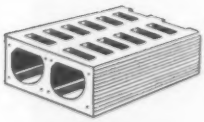
Why Trickling Filters Succeed for SEWAGE and WASTES TREATMENT



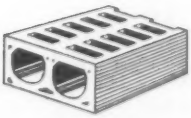
NATCO
Natco Corporation
Pittsburgh 22, Pa.



TRANSLOT
Connelton Sewer Pipe Co.
Connelton, Ind.



ARMCRE
Ayer-McCarel Clay Co., Inc.
Brazil, Ind.



BOSCO
Bowerston Shale Co.
Bowerston, Ohio

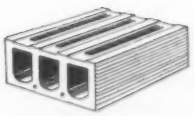
Nearly 1,000 new trickling filters went into service between 1945 and 1957. The building-pace continues unabated. This is a direct reflection of their economy in construction and efficiency in operation. For many of these filters are working as well today as when first built, even those thirty and more years old. Costly remodeling and rebuilding have been avoided. And no other type is easier to add to if growth exceeds your original estimate.

An important element in this success has been the vitrified clay underdrain blocks in the floors. Clay leads the field in its resistance to corrosive factors such as acids, alkalis and bacteriological action. TFFI Specification clay blocks not only serve right, they are made right—in modern plants under manufacturing controls of quality that substitute materials cannot even approach. (Only with TFFI blocks do you get a 50-Year Guarantee.)

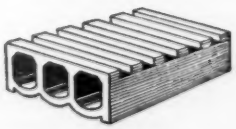
ENGINEERS:

If you have not received yours, write nearest member of this Institute for the new TFFI Trickling Filter Handbook containing also the new approved ASTM Specifications C 159-59T for your use in designing trickling filters.

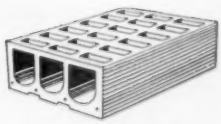
TRICKLING FILTER FLOOR INSTITUTE



POMONA
Pomona Terra-Cotta Co.
Pomona, No. Car.



TRANSLOT
Texas Vitrified Pipe Co.
Mineral Wells, Texas



DICKEY
W. S. Dickey Clay Mfg. Co.
Kansas City 6, Mo.

DORRCLONE® DEGRITTING pays off at High Point Treatment Plant, N. C.

Operating in combination with a 16′ dia. Dorr Detritor®, a 12″ dia. DorrClone washes 190 gpm of grit from the collecting tank underflow at North Carolina's High Point Sewage Treatment Plant. DorrClone degritting reduces subsequent treatment loads, improves overall capacity and efficiency. Equipment is simple, compact and has no moving parts. Plan above shows a typical installation. For more information, write Dorr-Oliver Incorporated, Stamford, Connecticut.

Consulting Engineer: Wm. F. Freeman Inc., High Point, N. C.
Contractor: F. L. Showalter, Inc., Lynchburg, Va.

DORR-OLIVER
WORLD-WIDE RESEARCH • ENGINEERING • EQUIPMENT

1959 Literature Review

A REVIEW OF THE LITERATURE OF 1959 ON WASTEWATER AND WATER POLLUTION CONTROL

By H. Heukelekian, *Chairman*, R. M. Manganelli, *Vice-Chairman*, E. J. Berg, H. F. Clark, C. H. Connell, W. E. Dobbins, G. P. Edwards, M. B. Ettinger, D. G. Foulke, T. deS. Furman, I. Gellman, H. Harding, C. Henderson, R. D. Hoak, P. E. Gaffney, W. M. Ingram, P. W. Kabler, M. Katz, F. W. Kittrell, N. J. Lardieri, H. G. Luley, P. H. McGauhey, W. A. Moore, N. L. Nemerow, R. Porges, E. R. Roth, A. J. Steffen, C. Straub, C. M. Tarzwell, W. W. Towne, H. A. Trebler, E. C. Tsivoglou, E. Weisberg, and R. L. Woodward

Research Committee, Water Pollution Control Federation

This last of three sections of the Literature Review covers water pollution. The first section, dealing with analytical methods and sewage, was published in the May 1960 issue of This Journal. The second section, on industrial wastes (including radioactivity), appeared in the June 1960 issue of This Journal.

WATER POLLUTION

Biology

Pollution Surveys and Investigations

Biological investigations of Hamburg Harbor by Caspers (50) reveal that completely depopulated areas occur in spite of the exchange of water due to tidal action. Where there is sedimentation of nutrient matter and sufficient current to remove oil and provide oxygen, there are large populations of tubificids. Formerly there were large populations of animals in the shallows below Hamburg but now all life is destroyed. Even the algae have disappeared. It is believed that oil and tar are chiefly responsible and that improvement can be obtained only by preventing the discharge of wastes into the harbor district.

At the present time according to MacLeod (147), water pollution is not widespread in British Columbia because of concentration of population and industry on the coast and large rivers, the small total population, and the undeveloped economy. Problems do exist in certain coastal areas. There has been contamination of oysters and other shellfish in Vancouver Harbor and there is pollution in the north arm of the Fraser River. Potential sources of industrial wastes are mining, wood industries, food processing plants, and petroleum refineries. Efforts are made to prevent the addition of pollutants to salmon streams which are of great value to the area. The oil refinery on the Thompson River (which has a $12-million sockeye run), treats its wastes

before discharging them. The character of the wastes must be such as to maintain the river at pH 6.7 to 8.6. In the past, salmon cannery wastes were harmful, but these materials are now being used for mink food. Surveys by Beak (32) have also been made in Ontario to determine the effects of wastes from industries in the Sarnia area. In these studies stress has been placed on the macro-invertebrates as indicators of environmental conditions. These organisms were classified into four groups and the relative abundance of organisms in each group was used as an indicator.

During recent years several surveys have been made to determine pollutional conditions in New Zealand (230). The Manawatu is polluted with sewage from several towns. An investigation was made of tidal influence on the composition of the water in an estuary having a narrow outlet to the sea. It was found that samples taken at low water levels gave the most information.

An extensive survey has been made (95) (96) (97) (98) of the Great Berg River in the Western Cape Province, South Africa. Physical and chemical conditions and the flora and fauna were studied by Harrison and Ellsworth (97). Quantitative studies were made of the bottom fauna of the main river and three tributaries by Harrison (98). Special attention was devoted by Scott (195) to the chironomids and 83 species were found in the river. Studies by Harrison (95) were also made of the effects of various degrees of organic pollution on the biota of the Great Berg and other streams.

A survey carried out in Czechoslovakia by Kubelka (128) indicated that industrial pollution is 20 to 50 times more severe than that from city sewage systems. Studies were carried out on Fure Lake, Denmark (17), to ascertain if changes had occurred since the surveys of 1900–1912. It was concluded that owing to increased sewage effluents the lake has become more eutrophic. It is pointed out that further changes in Fure Lake and other similar lakes will take place as the population increases even though the sewage receives conventional treatment at sewage works. A limnological study (191) was made of Vienna's water supply to determine if certain springs were being contaminated by surface waters. A study of the biota of the springs disclosed species characteristic of surface waters and thus indicated that surface water was contaminating the spring water.

The Freshwater Biological Association of Great Britain has carried on pollution work for a number of years. They are concerned with investigations of organic enrichment, natural purification, the effects of agricultural drainage on algal growths, and on the oxidation of bottom deposits (12). Work has been done on the rate of oxygen production by an aquatic plant at different light intensities and on methods for determining algal growth (13).

A Clean Streams Committee was formed in Cook County, Illinois, to locate sources of pollution and to work for their elimination. Birdsall (36) reports that most of the fish kills have been due to oxygen depletion. A study was made by Seabloom (196) of water quality characteristics in the Wenatchee River Basin to provide the basis for determining the effects of impoundment on water quality. It was found that the water was soft, well oxygenated, and in excellent condition.

Additional References

California, State of, "Oceanographic Survey of the Continental Shelf Area of South California." State Water Pollution Control Board, Sacramento, Calif., Publ. No. 20 (1959).

Clare, H. C., "Water Quality Problems in the Columbia River Basin." *Jour. San. Eng. Div., Amer. Soc. Civil Engrs.*, **85**, SA3, 1 (1959).

de Oliveira, Jejeune P. H., "Pollution of Marine Waters. Damages to the Flora and

Fauna of Rio de Janeiro." *Mem. Inst. Oswaldo Cruz* (Brazil), **56**, 1, 39 (1958); *Biol. Abs.*, **33**, 10, 36469 (1959).

Jaag, O., "Problems and Examples of Stream Protection in the Watershed of the Reuss River." *Wasser-und Energiewirtschaft*, 8–9, 12 pp. (1958); *Pub. Health Eng. Abs.*, **39**, 11, 23 (Nov. 1959).

Jaag, O., "Problems of Small Streams." *Schweiz. Z. Hydrol.* (Switzerland), **19**, 213 (1957); *Sport Fish. Abs.*, **3**, 202 (1958).

Nord, R. C., "Fisheries Survey of Upper Mississippi River." *Trans. Amer. Fish. Soc.*, **88**, 210 (1959).

Reish, D. J., and Barnard, J. L., "Marine Pollution." *Water and Sewage Works*, **106**, 6, 259 (1959).

Vivier, P., "Action of Waste Waters on Some Lakes and Rivers in France." *Bull. Centre Belge Etude et Document. Eaux* (Belgium), **43**, 32 (1959); *Pub. Health Eng. Abs.*, **39**, 11, 24 (Nov. 1959).

Wieser, E., "Water of Lake Constance and Water Supply." *Mitt. Ver. Dtsch. Gewässerschutz.* (Germany), No. 3/4, 10 (1958); *Water Poll. Abs.* (Brit.), **32**, 7, 1214 (1959).

Fish Kills

A severe fish mortality in Port Alberni Harbor, British Columbia, was found to be caused by dredging operations which released H_2S from an old deposit of cedar bark at the site of an old shingle mill (108). During 1958, 3 fish kills occurred in the Ruhr and 11 in tributaries. At least two of the kills were due to oil. It is believed that conditions in the Ruhr are improving (16).

Environmental Requirements for Aquatic Life

Settleable Solids

In considering the effects of the discharge of wastewaters to rivers without sedimentation, Beneden (34) states that very often the condition of the river bed is overlooked. Attention is directed to the supernatant water whereas the suspended material and the sediment accumulated on the bottom are often more harmful. The discharge of sludges can have far reaching effects. Highway construction can be very detrimental to streams, according to Whitney and Bailey (227). The removal of ground cover, the digging of cuts with resultant erosion, and building of the road up the valley without regard to the stream can result in the almost complete destruction of biological and aesthetic values. Fish population studies made in Flint Creek, Montana, before and after road construction showed that after construction there was a 94-per cent reduction in the number of large fish; an 85-per cent reduction in the number of small game fish; and a 76-per cent reduction in weight.

Turbidity and Light

Lackey (133) reports that silt exercises a restrictive effect on plankton algae, especially the *Chlorococcales, Euglenophyceae, Cryptophyceae,* and the blue-green and filamentous green algae. Certain *Volvocales, Chrysophyceae,* ciliates, and colorless flagellates are more resistant. It also restricts *Charales, Utricularia, Potamogeton,* crustaceans, snails, insect larvae, and fishes. In the White River of Indiana, at a turbidity of 33 mg/l, there were 67,459 plankters per ml, but at 115 mg/l, only 188 were found. Laboratory studies indicate that silt carries the plankton down and buries it. Fine sand of 74 to 140 μ carried down 20 *Euglena* for every 3 left; muck carried down 51 of 83; whereas clay carried down all but 1 out of 530 per ml.

The effects of wave length, energy, temperature, the distribution of radiant energy, and absorption and scattering on photosynthetic productivity are discussed by Strickland (204). A three-year study by Burrows (47) of the effects of light on the sexual maturation of adult blueback salmon revealed that the periodicity of light influences spawning time and may be a prime factor. The control salmon spawned at essentially the same time each year though the temperature was 2.5°F lower in 1955 than in 1956 and 1957. Salmon exposed to artificial

light spawned at temperatures 5°F lower in 1955, and 2°F higher in 1956 and 1957, as compared to temperatures for the controls. The various species of fishes react to light differently during their development and during the seasons of the year (177).

Dissolved Solids

Houston (109) studied the responses of juvenile chum and pink salmon fry and coho fry and smolts to sharp sea water gradients in tanks. Fresh water control experiments indicated the presence of some factor or factors which resulted in preferences for "recognized" areas. Studies were made by Herbert and Mann (103) to determine the tolerance of roach and perch to sudden increases in salinity. Perch could withstand about 45 per cent sea water for several days, whereas roach could tolerate only about 30 per cent.

Field observations were made by Chipman (53) on a pond which received brine water from oil operations. The fish could not escape and counts of dead fish were made over a 7-day period. The fish killed by the high salt content were of freshwater origin. In studies with oil field brines carried out in Arkansas by Wood (232), it was found that the 24-hr TL_m for bluegills varied from 10,500 to 8,100 mg/l total chlorides, depending on the formation from which the brine came. Tolerance was greatly reduced as the period of exposure was increased. Calcium chloride was more toxic than NaCl and an equal mixture of the two salts was less toxic than either individually. Mayfly nymphs had a 24-hr tolerance limit of 10,000 mg/l chlorides which dropped to 3,600 mg/l at 72 hr.

Tucker (214) studied the distribution of some freshwater invertebrates in ponds in relation to the annual fluctuations in the chemical composition of the water. He found that fewer species occurred in small soft water ponds than in the larger hard water ponds.

Temperature

Temperature has diverse and involved effects on aquatic life, as reported by La Berge (132). For most organisms there are optimum, tolerable, and critical temperature levels. Temperature affects oxygen requirements, metabolism, the speed of action of toxic materials, and the speed of self-purification. Unfavorable temperatures, as opposed to lethal temperatures, may cause a species to disappear due to the fierce competition existing among the stream's population. Ferguson (80) reports the level of thermal acclimation influences the range of temperature preferred. In general the preferred temperature is much higher than the acclimation temperature at low thermal acclimations but this difference decreases up to the final preferendum when both coincide. The final preferendum of yellow perch was 24.2°C. Summer field observations of yellow perch in Lake Nipissing, Costello Lake, and Opeongo Lake in Ontario showed average thermal distribution at 19.7, 21, and 21.2°C, respectively. This agrees well with 20.8°C, observed for four Wisconsin lakes. Studies by Garside and Tait (87) showed that in most species of fish, the selected or preferred temperature is directly related to increasing acclimatization temperature. However, with the rainbow trout the preferred temperature decreased with increase in acclimatization temperature. The modal preferred temperatures of trout acclimatized to 5, 10, 15, and 20°C, were determined photographically to be 16, 15, 13, and 11°C, respectively.

Laboratory experiments by Dickie (72) show that scallops living in water between 5 and 20°C may be killed by temperatures of 21 to 23°C. Scallop mobility is markedly reduced by sudden temperature changes. While acclimation to rising temperature is relatively rapid (2 or 3 days) adjustment to reduced temperature is exceedingly

slow (over 2 months). In experiments carried out on the temperature tolerance of eggs and young of whitefish from the Columbia River, it was found that mortality increased with increase in temperature (14). In the initial stage of independent nutrition the young of the Ladogian salmon showed faster growth and greater utilization of food at 7 to 8°C, and the young of the rainbow trout at 14 to 18°C (152). For the young of the Ladogian salmon at the age of 60 days, 15°C was optimal for growth.

In studies to determine the cruising speed of underyearling and yearling sockeye and coho salmon, acclimated to various temperatures, Brett *et al.* (42) found that the optimum temperature for sockeye was 15°C and for coho, 20°C. Maximum sustained swimming levels fell mainly between 1.0 and 1.5 fps. Exercised young coho showed improved performance over those raised in standard hatchery troughs. Aquatic, gill-breathing vertebrates cannot escape from environmental temperatures (43). Tissue and environmental temperatures are constantly equilibrated at the gill surfaces and an external temperature best suited to the internal tissues is essential for the general well being of the organism. In studies to determine the effects of temperature on the formation of vertebrae and fin rays in young chinook salmon, Seymour (197) found that there were no survivals to the stage where vertebrae or fin rays could be counted for lots reared at temperatures below 39°F or above 62°F.

In experiments to determine the effects of temperature on the lethal dose and the progress of the toxic action of certain chlorinated hydrocarbon insecticides, Adlung (2) found that temperature had little effect on the absolute lethal dose but a decrease in temperature delayed the progress of the toxic action. The critical period after which damage done to the fish was not reversible on transfer to clean water was 25 times as long at 4 and 11°C as at 19°C.

Studies have been made by Vliet (218) of the effects of heated condenser discharge water on the aquatic life of the Delaware River. It was found that large numbers of fish were attracted to the warm water zone in winter and fishing was exceptionally good in this area. During the summer months as the water became progressively warmer fish left the heated water area. Certain blue-green algae and chironomids appeared to be stimulated by the hot waters but most of the larger aquatic insects were inhibited.

Oxygen and CO_2

In studies of a prairie lake by Moyle and Clothier (159) it was concluded that walleyes and perhaps channel catfish and bluegills did not survive as well at winter oxygen levels below 5 ppm as above this level. Northern pike, crappies, and rough fish were more tolerant and evidently survived when winter DO levels fell to near 1 ppm. Observations by Barber (27) on the DO content in the deeper waters of Queen Charlotte Sound, British Columbia, showed that concentrations of less than 2 mg/l occurred in the summer. It is considered that these levels are lethal to the local freshwater fishes.

Basu (31) measured oxygen consumption at a steady rate of activity for the brook trout, common sucker, brown bullhead, carp, and goldfish in the presence of various combinations of oxygen and CO_2. The sensitivity to CO_2 decreases with increasing acclimation temperature. The oxygen concentration determines the level of active oxygen consumption in the absence of CO_2. When the oxygen concentration approaches the lower lethal limit, the effects of the addition of CO_2 are enhanced. In experiments performed in the fall by Davison *et al.* (70), minimum oxygen concentrations tolerated for one day by juvenile coho salmon

changed little with temperatures between 12 and 20°C, but increased markedly at higher temperatures. At a constant temperature of 20°C they tolerated for a day oxygen concentrations below 2 mg/l but above 1 mg/l. Yearling coho salmon tested in winter lived for 30 days at temperatures near 18°C and oxygen concentrations averaging 2 mg/l but were sluggish, consumed little food, and lost weight. At concentrations of 2.9 mg/l the fish fed well and gained weight but were probably adversely affected.

With a rapid reduction of oxygen content in the water the gaseous exchange of the fry and young of the sturgeon (*Acipenser guldenstadti* and *A. stellatus*) was maintained at a constant level down to 3 mg/l, after which there was a sharp reduction in gas exchange (145). Growth, food consumption, and food coefficient were changed at a higher level of DO. The young can adapt to a lowering of the DO level over considerable periods.

The respiratory intensity of fishes varies with age. In a study of the intensity of respiration in pike during the first year of life, it was found that the respiratory intensity increased rapidly at the start of growth and then decreased (198). In young pike of 7 to 8 mm, the respiratory intensity equalled 0.8 mg O_2 per g of dry weight per hr. It reached 1.9 mg O_2 in the young during increased activity. The greatest respiratory intensity was in 17- to 18-mm long pike—10 mg O_2 per g per hr. At a length of 60 to 70 mm the rate had decreased to 2 mg O_2 per g dry weight and at a length of 300 to 600 mm had decreased to 0.4 to 0.8 mg O_2 per g of dry weight. The oxygen consumption of milk fish *Chanos chanos* was measured by Job (114) with fish ranging in weight from 0.7 to 11 g at temperatures of 25 and 29°C and at oxygen tensions of 300 mm Hg down to almost asphyxial levels. The critical tension of oxygen at which uptake of the gas became dependent on the available oxygen was near the air saturation level at the acclimation temperature of 29°C. Studies were made by Allan *et al.* (11) on fish kept in the undiluted effluent from a sewage treatment plant. Results showed that mortality was due mainly to low oxygen concentrations and that free CO_2 appreciably increased the sensitivity of fish to low oxygen levels.

Tests were made by Katz *et al.* (116) to determine the ability of certain species of fish to swim against currents of 0.8 and 1.2 fps for a period of 2 days at different DO levels. The ability of the juvenile chinook salmon to swim against these currents is dependent on their size. Only those over 50 mm long were able to swim for a day against a current of 1.2 fps even when the DO was near the saturation level. At DO levels of 3 mg/l juvenile chinook salmon could swim for a day against a current of 0.8 fps. In all tests at DO concentrations less than 2.84 mg/l only some fish were able to swim for a day. At oxygen levels between 2.0 and 2.7 mg/l, some of the juvenile cohos were able to swim against a current of 0.8 fps for two days. In September, largemouth bass were able to swim against a current of 0.8 fps for one day at 25°C in water having a mean DO content of 2 mg/l. In December, at 15.5 to 17°C, they could swim against the 0.8-fps current when DO was near saturation, but they were unable to do so when the DO was reduced to 5 mg/l. Studies by Itazawa (111) of the relation of the gas content of the blood of carp to that of the water revealed that the oxygen content of arterial blood increased with oxygen tension up to about 80 mm of Hg, and ranged between 0 and 9.54 per cent by volume. When the oxygen content of the arterial blood decreased to less than 2 per cent by volume the carp showed symptoms of dyspnoea; this corresponds to an oxygen tension of about 15 mm of Hg.

Studies of the mortality of spawn

and fry of carp during transportation indicated that spawn could stand a concentration of 20 mg/l CO_2, 2.5 mg/l free NH_3, and 15 mg/l dissolved NH_4 in the form of salts (187).

In laboratory experiments with *Daphnia obtusa* the mean oxygen consumption at 15°C was 4.05 ± 0.20 μg per individual per 24 hr (219). A direct relation was found between oxygen consumption and the temperature of the water. As reported by Lumbye (146) the oxygen consumption of the molluses, *Theodoxus fluviatilis* and *Potamopygus jenkinsi* are decreased as the DO decreased. The former species shows increased oxygen consumption with increase in temperature up to 29°C in fresh water and up to 35°C in brackish water. Further increases in temperature result in a sharp drop in oxygen consumption. The oxygen consumption of the prawn, *Metapenaeus monoceros*, increases with a decrease in salinity below that of the normal habitat (179). Mann (149) states that in summer, leeches can become acclimatized to DO levels down to one-third air saturation but this acclimatization does not occur in winter. After a meal the oxygen consumption increases threefold. Experiments by Edwards (75) with *Chironomus riparius* indicated that the rate of oxygen consumption was greater at 20 than at 10°C.

Additional References

Anon., "The Influence of Carbon Dioxide and pH on the Dissolved Oxygen Requirements of Some Fresh Water Fish." Natl. Council for Stream Improvement Tech. Bull. No. 123 (Sept. 1959).

Barth, H., "Assimilation and Output of Carbon Dioxide and Oxygen by Submerged Water Plants." *Limnol. Schriftenreihe*, **4**, 17/18, 18 (1957); *Water Poll. Abs.* (Brit.), **31**, 372 (1958).

Bulse, G., "Experiences in Measurement of Conductivity and Determination of Hardness in the Assessment of Quality of Waters." *Arch. Fischwiss.*, **9**, 17 (1958); *Water Poll. Abs.* (Brit.), **32**, 156 (1959).

Buscemi, P. A., "Littoral Oxygen Depletion Produced by a Cover of *Elodea canadensis*." *Oikos*, **9**, 239 (1958); *Water Poll. Abs.* (Brit.), **32**, 192 (1959).

Cole, B. T., Bennett, H. J., and Miller, J. D., "Tolerance of Euryhaline Fish Forms to Dilution of Oil Field Bleed Water." *Proc. La. Acad. Sci.*, **20**, 13 (1959); *Biol. Abs.*, **33**, 2, 8805 (1959).

Gameson, A. L. H., "Some Aspects of the Carbon, Nitrogen, and Sulphur Cycles in the Thames Estuary. II. Influence on the Oxygen Balance." Symposium on Effects of Pollution on Living Material, Inst. of Biology, London (Sept. 1958); *Water Poll. Abs.* (Brit.), **32**, 2, 70 (1959).

Gessner, F., and Pannier, F., "The Oxygen Demand of Water Plants at Different Oxygen Tensions." *Hydrobiologia* (Denmark), **10**, 323 (1958); *Water Poll. Abs.* (Brit.), **32**, 44 (1959).

Gilchrist, B. M., "The Oxygen Consumption of *Artemia salina* (L.)." *Hydrobiologia* (Denmark), **12**, 27 (1958); *Water Poll. Abs.* (Brit.), **32**, 14 (1959).

Herbert, D. W. H., and Mann, H. T., "The Tolerance of Some Fresh-Water Fish for Sea Water." *Salmon and Trout Magazine* (May 1958).

Huet, M., "Correlation Between the Biological and Chemical Analysis of Polluted Waters." *Intl. Ver. Theoret. u. Angew. Limnol., Verhandl.*, **13**, Pt. 2, 584 (1958); *Chem. Abs.*, **53**, 4, 3557 (1959).

Jullien, A., Ripplinger, J., Cardot, J., and Dury, M., "Influence on Survival Time of the Freshwater Fish *Leuciscus rutilus* of Variations in the Ionic Ratios in Solutions Containing the Three Cations, Sodium, Potassium, and Calcium." *Compt. Rend. Soc. Biol.* (France), **152**, 1545 (1958); *Chem. Abs.*, **53**, 15384 (1959).

McFarland, W. N., and Norris, K. S., "The Control of pH by Buffers in Fish Transport." *Calif. Fish and Game*, **44**, 4, 291 (1958); *Biol. Abs.*, **33**, 6, 20746 (1959).

Roen, U., "Contributions to the Biology of Some Danish Free-living Freshwater Copepods." *Biol. Skr.*, **9**, 102 pp. (1957); *Water Poll. Abs.* (Brit.), **32**, 5, 815 (1959).

Ross, F. F., "The Operation of Thermal Stations in Relation to Streams." *Jour. and Proc., Inst. Sew. Purif.*, Part 1, 16 (1959).

Saha, K. C., Sen, D. P., and Mazumdar, P., "Studies on the Mortality in Spawn and Fry of Indian Major Carps During Transport. II. Effect of Oxygen Pressure, Free Surface Area, Water Volume, and Number of Fry in the Medium of Transport." *Indian Jour. Fish.*, **3**, 127 (1956); *Sport Fish. Abs.*, **3**, 143 (1958).

Toxic Materials and Wastes

Bio-assays are being more widely used for the detection and evaluation

of toxicity problems. By the use of bio-assays it is possible to take into consideration and evaluate water quality characteristics which influence the toxicity of a waste. The short term bio-assay indicates the concentration of a waste which will kill half the test fish in a specific time. Since the aim is not to save just half the fish but to make conditions safe for all the fish under conditions of continuous exposure, it is necessary to apply an application factor to the TL_m values obtained in the short term tests (209).

Clemens and Sneed (57) have made bio-assays with 60 chemicals to determine the amount of each which will kill all the fish, half the fish, and the amount tolerated by the fish for periods of 1 to 96 hr.

Bio-assay Methods

Hermann (15) has developed a bio-assay procedure for determining the toxicity of wastewaters through the use of bacteria, grown on a standard medium, as the test organism. Forty-eight hour brine shrimp have been successfully used as test organisms in bio-assays to indicate the toxicity of wastes (169). Tests are run for 24 hr at 20°C. Tarpley (208) also used the brine shrimp as a test organism for bio-assays to determine insecticide residues. Methods were developed for the rearing of the animals so they would give consistent results. Rock salt at a concentration of 3.5 per cent was used. Tests were run at 27.5°C. Boyd (40) used *Daphnia magna* as the test organism in the bio-assay of a number of organic insecticides. On the basis of these studies it was concluded that *Daphnia magna* can serve as a satisfactory test organism for the bio-assay of micro amounts of insecticide. Bio-assays were run by Schiffman and Fromm (190) on young kelp blades in gallon glass jars using fresh filtered sea water as a dilution water. Oxygen production of disks cut out of the fronds was used as a measure of damage by the toxic material. Oxygen was determined manometrically. This test was found to show damage before any physical damage was evident. The authors believe there is a possibility of using physiological damage rather than mortality as an endpoint in bio-assays to evaluate the effects of wastes on fishes. While the 24-hr TL_m of K_2CrO_4 to rainbow trout adults was about 160 mg/l Cr, only 20 mg/l Cr raised the hematocrit of both splenectonized and intact fish. Exposure of fish to 2 to 4 mg/l Cr raised the hematocrit to its maximum value. Weiss (225) employed the *in vivo* inactivation of fish brain acetylcholinesterase to demonstrate the presence of low concentrations of organic phosphorus insecticides. He found that the *in vivo* inhibition of acetylcholinesterase by the organic phosphorus insecticides was a function of concentration of the insecticide, the extent of exposure, and the specific chemical nature of the inhibiting substance. It was shown that the specific *in vivo* response of acetylcholinesterase to low concentrations of organic phosphorus insecticides permits the assay of current as well as past pollution by these materials. Weiss (224) also found that by utilizing the most sensitive species concentrations as low as 0.1 mg/l may be detected with 12- to 24-hr exposure. Compounds such as parathion, diazinon, and delnav produced marked inhibition of enzyme activity in as little as 6 hr in several species of fish.

Metals

Wastewaters containing appreciable amounts of Cu and NH_4 ions are discharged into Lake Orta in northern Italy from an artificial silk factory (61). When the wastes were first introduced all plankton, benthic fauna, and fish were killed. Copper is found in the upper 6 cm of bottom sediment. There is a fairly good correlation between Cu, organic matter, and chlorophyll content. *Cyclotella* and *Fragi-*

laria, once most abundant in the lake, have greatly decreased and *Achnanthes nodosa* has become dominant in competition with species less tolerant of Cu.

Rainbow trout fry were greatly affected by $CuSO_4$ concentrations slightly above 3 mg/l and some toxicity was shown at concentrations of 1 mg/l (215). At 10 mg/l, $CuSO_4$ caused 90- to 100-per cent mortality in 12 hr. *Daphnia magna* was killed by 1 mg/l while the larvae of the gnat *Simulium dentalosum* were unaffected by 10 mg/l $CuSO_4$. Clendenning (58) found that copper at 1 mg/l completely stopped photosynthesis in kelp in 48 hr. At 0.1 mg/l Cu decreased photosynthesis 50 per cent in 2 to 5 days and over 70 per cent in 7 to 9 days. Chromium and Cl were much less toxic than Cu to kelp. It required more than 10 mg/l of Cr and Cl to produce the same symptoms as 1 mg/l Cu.

Investigations of the toxicity of Cr to fish (14) showed that hexavalent Cr in a concentration of 0.2 mg/l was definitely toxic, retarding rate of growth, and resulting in increased mortality. Trivalent Cr in the same concentration had no observable effect.

Surber (207) reported that in polluted stretches of Michigan rivers, larvae of the midge, *Cricotopus bicinctus*, were found to be particularly resistant to electroplating wastes containing hexavalent Cr, CN, and Cu at low DO levels. In the Clinton River they matured in concentrations of Cr as great as 25 mg/l; Cu to 2.2 mg/l, and cyanides to 3.2 mg/l. In such situations the only other common benthic invertebrates present were the annelids, *Limnodrilus* and *Tubifex*, and a midge, probably *Pentapedilum*.

Sweitzer Reservoir near Delta, Colorado, has been stocked repeatedly with a variety of game fishes since 1954, as discussed by Barnhart (28). Almost a complete mortality has occurred after each introduction. Tests showed that unusual concentrations of As, Se, U, and Zn existed in the drainage area and that bottom deposits in the deep portions contained extremely high concentrations of Se. Certain plants and animals contained excessive amounts of Se and the livers of flannelmouth suckers and round tail chubs native to the area contained Se at levels toxic to some mammals. It is believed that Se is passed up through the food chain to the fish which accumulate the element in lethal concentrations.

Studies by Lawrence (135) showed that in experimental ponds two applications of 4 mg/l $NaAsO_2$ applied one month apart reduced the number of bottom organisms an average of 34 per cent and reduced bluegill production an average of 42 per cent as compared with those of control ponds. Two applications of 8 mg/l $NaAsO_2$ applied one month apart reduced the number of bottom organisms an average of 45 per cent and the bluegills 65 per cent as compared with production in control ponds. An application at 4 mg/l killed all the microcrustacea and greatly reduced the population of rotifers.

Bio-assays with several zirconium salts gave 48-hr TL_m values of approximately 15 mg/l in soft water and 200 mg/l in hard water (173).

Phenolic Compounds

The accidental discharge of a waste having high phenol content resulted in an extensive fish kill in the river Kura (120). The effluent from the plant contained 77 mg/l phenol and in the dead fish the concentration of phenol was 0.1 to 6.3 mg/kg. On the next day the river downstream from the plant contained 0.055 mg/l phenol.

Albersmeyer and Erichsen have dealt with the toxicity of phenolic compounds to aquatic life in a series of seven papers (4) (5) (6) (7) (8) (9) (10). It was concluded that the phenols are nerve poisons with similar modes of action but they demonstrate in some ways clearly different symptoms in poisoned fishes. Fish that lose

their equilibrium in toxic concentrations can recover when placed in fresh water, with the exception of those subjected to phenol which do not recover. A permanent disabling effect is noted in solutions of pure phenol solutions much sooner than in cresol and xylenol. The 24-hr LD_{50} of the various phenolic compounds under study was determined for certain fishes. The results of these studies are summarized in Table I. The toxicity of these materials to *Tinca vulgaris* and *Leuciscus rutilus* was in the same order of magnitude as that for *Carassius vulgaris*.

It will be noted that these materials were much more toxic to rainbow trout. The LD_{50} values were also determined for a number of aquatic invertebrates. From the results of these studies it was concluded that the concentration required to elicit a reaction from the most sensitive of the invertebrates studied is significantly greater than the lethal concentrations for fish. The approximate reaction thresholds of the species studied are shown in Table II.

There are considerable differences in the uptake of the different phenols which can be correlated with toxic symptoms, time of reaction, and toxicity. Studies on the tainting of fish flesh by means of organoleptic tests show little connection between uptake

TABLE I.—Toxicity of Phenolic Compounds to Fish

Material	24-hr LD_{50} (mg/l)	
	Carassius vulgaris	Rainbow Trout Embryos*
Phenol	24.9	5.0
o-cresol	29.5	2.3
m-cresol	24.5	6.5
p-cresol	21.2	4.0
1-2-4-xylenol	21.1	4.0
1-3-4-xylenol	30.0	27.7
1-3-5-xylenol	53.0	50.0
1-4-5-xylenol	10.0	2.0

* Tests run at 15°C.

TABLE II.—Approximate Reaction Thresholds for Certain Fish Species

Species	Approximate Reaction Thresholds (mg/l)		
	Phenol	m-cresol	1-4-5-xylenol
Culex larvae	40–50	20–30	15–20
Culex pupae	800–1,000	700–800	300–350
Sayomia plumicornis larvae	150–180	80–100	30–40
Pionocypris vidua	100–120	90–100	30–40
Cyclops strenuus	150–180	100–120	20–30
Daphnia pulex	50–60	30–40	15–20

of the various phenols and the influence on the taste of the fish flesh. These investigations indicate that the intense taste change is not caused by the storage of phenols in the body of the fish but is due to the non-phenolic substances that accompany the phenols in wastewaters. Taste tests with some aromatic, neutral phenol impurities gave an intense taste. The carbolated oils and the light oils gave a quicker and more rapid toxicity than did the naphthalenes and a-methylnaphthalenes that were also found as accompanying substances in the phenolic wastes.

Studies were also made of the effects of the same phenolic compounds on the sperm and ripe eggs of some European fishes. The sperm and eggs were not harmed by concentrations which were tolerated by the adults. Harm was first noted at about 50 mg/l and in contrast to the adults there was no significant difference in the toxicity of the various compounds studied. Eggs of *Carassius vulgaris*, *Tinca vulgaris*, and *Gasterosteus pungitius* were used in the studies.

It was found that the toxicity of certain of the phenols to some forms of the saprobic system is of importance in biological self-purification of polluted waters. However, the results show that in general the resistance to the phenols increases with decreasing complexity of the organisms.

The reaction of roaches in stepped concentration gradients of 2, 4, 6-trinitrophenol was studied in a fluviarium

by Lindahl and Marestrom (141). This species is attracted by this substance at concentrations lower than 3×10^{-4} M and they prolonged their stay in the higher concentrations. Their responsiveness varied with body length and age. The 24-hr TL_m for pentachlorophenate to fathead minnows was found by Crandall and Goodnight (63) to be between 0.32 and 0.35 mg/l. All fish were killed at 0.4 mg/l while all lived at 0.2 mg/l. As the pH was lowered the material became more toxic, and as the temperature was raised the material became more rapidly toxic.

Pulp and Paper Mill Wastes

Paper mill wastes discharged to the Karnaphuli River of Pakistan reduced DO levels to 1 mg/l for a distance of 2 miles downstream (54). The waste affects the gills and eyes of the fish and taints the flesh. Studies carried on at Bowman's Bay by Neale (161) indicate that threshold mortality levels for downstream migrants of chinook and pink salmon are 500 to 600 mg/l of sulfite waste liquor during continuous exposure for 30 days. Adverse effects occur at much lower concentrations. The presence of 50 mg/l sulfite waste liquor can cause a depressing effect on some species of marine fish food organisms and much smaller concentrations can cause abnormal growths of *Sphaerotilus*.

When a kraft paper mill began operations and discharged its wastes to the Clark Fork River near Missoula, Montana, fish kills resulted (228). With caged trout the mortality was 25 per cent, 2 miles downstream. Bottom organisms were reduced in number and the makeup of the population was changed. *Sphaerotilus* growths increased greatly in a three-fourth mile stretch of the river. Seven commercial formulations used for controlling slime by the pulp and paper industry were found by Stammer (201) to be toxic to rainbow trout yearlings.

Pesticides

According to Tarzwell (211) the use of synthetic organic pesticides has been increasing steadily. Each year new materials are placed on the market and new uses are found for the materials. Total annual sales of all formulations now amount to billions of pounds. Usage has become so great that these materials are being carried into streams by runoff and many fish kills have resulted. Synthetic organic pesticides now must be considered as water pollutants. Much study is needed to determine the effects of widespread area spraying programs. In the extensive use of any pesticide consideration should be given to its over-all pollutional potential such as its residual toxicity, its persistence in the soil, its contamination of surface runoff and seepage, and its effects on terrestrial and aquatic organisms.

Dinitrocarbazole as a 10-per cent dust is used for forest spraying in some areas (1). Experiments with minnows showed that dust applied at the rate of 2.5 kg/hectare caused death in 12 to 15 hr and 5 kg/hectare caused death of fish in 5 to 6 hr. The normal rate of application has been 50 kg/hectare. Tarzwell (210) reports that the chlorinated hydrocarbon insecticides are in general much more toxic to fishes than are the organic phosphorus insecticides. With the exception of BHC all the chlorinated hydrocarbons tested were significantly more toxic to fishes than were the organic phosphorus compounds. Endrin, Toxaphene, and Dieldrin are extremely toxic to fish and even very small amounts can be damaging when applied to water surfaces. On the basis of laboratory studies the following amounts of these materials would kill half the fish in 96 hr when applied to 1 acre of water, 3 ft deep; i.e., 3 acre-ft, Endrin, 0.005 lb; Toxaphene, 0.03 lb; and Dieldrin, 0.07 lb. Insecticides are now so widely used that they resemble silt as a pollutant

in that they may be washed into the stream from large portions of the watershed. Insecticides have already been found in large rivers. The only means of control is control at the source; to limit their application, or to use materials which do not interfere with beneficial water uses.

In studies by Webb (221) of potential herbicides it was found that heptachlor, Phygon X-L, Sinox, Aquatic Weed Killer, and malathion all represent potential hazards to fish life. Karmex W, Dowpon, and amino triazole do not appear to represent a major toxicity problem unless carelessly handled or used in overdoses. In New York State studies were made by Eipper (76) of 5 herbicides over a 3-yr period. With respect to treatment cost and safety of small fish, $CuSO_4$ had definite advantages over Delrad and Fermate. Phygon at 0.25-mg/l concentration killed neither fish nor plant growths.

The brine shrimp was found by Tarpley (208) to be susceptible to DDT, parathion, and Dieldrin in the order named. The larvae of *Aedes aegypti* were more susceptible to these materials than was the brine shrimp.

It is suspected by Nicholson (164) that a substantial amount of several of the stable chlorinated hydrocarbon insecticides wash off the crops and land and find their way into inland waters. Tests were conducted by Keenleyside (117) on young Atlantic salmon, 3.5 in. long, with DDT and malathion in a solvent oil in the same proportions used in aerial sprays for the control of spruce budworm. The 24- and 48-hr TL_m values obtained were 0.049 and 0.047 mg/l for DDT, and 0.033 mg/l for malathion for both periods. The effects of forest spraying with DDT on the aquatic life of the streams in sprayed areas were investigated by the Fisheries Research Board of Canada (119). DDT in oil spraying in northern Vancouver Island resulted in the killing of many coho salmon fry and young steelhead trout. Fish and fish food organisms were studied in 13 Montana trout streams by Graham and Scott (89) to find the effects of an aerial spray of 1 lb DDT/acre that was applied in 1956 for the control of spruce budworms. Benthic invertebrates and adult insects were materially reduced. DDT was present in trout tissues after 16 months. Fish declined 70 per cent in one stream and 80 per cent in another. In New Brunswick, forest spraying resulted in a complete loss of small salmon in test areas in 1954, and severely depleted the large aquatic insects (118). Crouter and Vernon (65) discussed an aerial spraying made in mid-June of 1955 of timberland in the northern part of Vancouver Island for the control of the black-headed budworm. Dosage was at the rate of 1 lb of DDT/acre. The damage to fish and fish food organisms was severe. Mortality was confined to coho fry, trout, steelhead yearlings, and possibly alevins of trout and steelhead. Bio-assay tests indicated that a safe concentration of the formulation used in the control program would be below 0.05 mg/l. Analysis of water samples showed that toxic concentrations of DDT existed in the stream for more than three days after spraying.

Eight lakes were treated with Toxaphene at concentrations ranging from 0.10 to 0.01 mg/l (205). Most of the fish were killed at all concentrations within the first 120 hr. Nine months after treatment no fish were present in the lakes and they were still toxic to fish. Amphipods were eliminated at all the test concentrations and were still absent 9 months later. Dragonfly and damselfly nymphs and midge larvae were killed by 0.03 mg/l. Toxaphene used for field mice control was washed into a stream and killed fish (26).

An application of 2 lb/acre of Heptachlor near Sour Lake, Texas, resulted in a fish kill over a period of 3 weeks

as reported by Boudreaux *et al.* (39). Young fish died first. Henderson *et al.* (101) reported that bio-assays conducted with 10 commonly used chlorinated hydrocarbons on 4 species of fish showed that toxicity varied somewhat with the species but all except BHC were extremely toxic and 96-hr TL_m values ranged as low as 0.6 μg/l. Bluegills were the most sensitive fish followed by fathead minnows, goldfish, and guppies. Changes in water quality characteristics had no apparent effect on toxicity.

Weiss (224) states that fish brain acetylcholinesterase is inhibited *in vivo* by organic phosphorus insecticides in dilute aqueous solutions. Fish removed from exposure prior to reaching lethal limits demonstrate the capacity for regeneration of the enzyme. Time required for regeneration to normal levels will depend on the extent of the initial inhibition, the specific chemical involved, and the species of fish. The period necessary for regeneration may be in excess of 30 days. Only parathion produced a continued decrease in brain acetylcholinesterase after removal from exposure (225). Malathion and EPN when used in combination exhibited a marked synergistic effect.

A series of field tests were made by Darsie and Corriden (68) to ascertain the toxicity of malathion to killifish in the tidal marshes of Delaware. Aerial sprays were used to simulate actual mosquito control procedures with applications at the rate of 0.5 lb/acre. Fish were exposed to the toxicant for only 4 hr after which they were placed in fresh water and inspected 20 and 64 hr later. It is believed this procedure largely nullified the tests as under natural conditions fish are not removed from treated areas. In spite of this procedure 26.3 per cent died.

Tests were carried out by Hoffman (105) to determine if effluents from drainage systems where fly control material had been used would be dangerous to fish. Parathion in concentrations of 0.05, 0.1, 0.5, and 1.0 mg/l did not damage brook and rainbow trout in the tests so the concentration used in insect control, 0.01 mg/l, should be harmless. Phosdrin killed all test fish at 0.05 mg/l and produced symptoms of poisoning at 0.01 mg/l after 180-hr exposure. Dipterex caused no damage at 1 to 10 mg/l and is thus not considered dangerous.

Toxic Materials Produced by Algae

Tests by Ray and Wilson (181) of the toxicity to fish of unialgal and bacteria-free cultures of *Gymnodinium brevis* containing 0.6 to 4.8 million algae per liter demonstrated no difference in toxicity. This indicated that this dinoflagellate is the direct cause of mass mortalities of fish and other marine animals associated with blooms in the Gulf of Mexico. The toxicity of *G. brevis* does not depend on the presence of the living organisms. In studies by Reich and Rotberg (182) with *Prymnesium parvum* it was found that more toxin is formed in 5-per cent sea water than in 30-per cent sea water. This explains the fact that fish mortalities have been observed only in brackish water even though *Prymnesium* also occurs in the sea. The addition of Ca to the culture increased the amount of toxin formed. The death of fish due to red tide was observed by Numann (166) in the Bay of Luanda, Portuguese West Africa, and in the Bay of Izmir, Smyrna. The red tide is caused by a mass development of certain organisms in waters rich in nutrient matter. Such developments are stimulated by substances carried in by fresh waters.

Waldichuk (220) reported that an outbreak of shellfish poisoning in the Straits of Georgia, British Columbia, during October 1957, was caused by the consumption of mussels, clams, and oysters. It is believed that unusual weather conditions were responsible for the production of the plankton organisms which produce the toxicity in

the shellfish. The oysters cleared themselves of the toxicity in about 6 weeks but the clams remained toxic until the next spring. Catastrophic outbreaks of poisonous dinoflagellates have been reported from many coastal areas throughout the world (110). They have killed large numbers of fish and other aquatic animals, and shellfish contaminated by their poisons have caused illness and death to humans.

Other Toxic Materials

In the mining of gold and coal in the Transvaal, South Africa, pyrites are exposed to the air with a resulting production of H_2SO_4, much of which drains into streams and causes severe pollution (98). It was found that mineral acid tends to produce the same peat bog conditions as do poorly mineralized waters containing humic acids. Specialized flora and fauna develop when the pH falls below 5.0 and have been observed at pH values as low as 2.9.

Sodium nitrite is used in metal works and in the manufacture of dyes, celluloid, and explosives. Concentrations of more than 100 mg/l of this material have been found in streams receiving wastes from the above processes (125). Tests with minnows showed that 50 mg/l could be fatal in 14 days. It is believed that $NaNO_2$ destroys the blood pigment and damages the central nervous system.

In experiments with model reservoirs, pyridine was found to inhibit the self-purification process when present at a concentration of 1 mg/l but not at 0.5 mg/l (239). At a concentration of 2.5 mg/l, pyridine gave the water a characteristic odor. It is suggested that the maximum permissible concentration of pyridine in the water of reservoirs should be 0.25 mg/l.

Bio-assay tests were run by Cairns and Scheier (48) with 10 substances to determine if there were any differences in toxicity of these materials to 3 different sizes of bluegills. Average length and weight of each of the 3 sizes of bluegills were: 3.88 cm—0.96 g; 6.09 cm—2.8 g; and 14.24 cm—54.26 g. Tests were run at 20°C. Substances tested were $CaCl_2$, KCN, $NaNO_3$, cresol, Na_2CO_3, $NaHCO_3$, Na_2SO_4, $ZnCl_2$, NH_4Cl, NaOH, HCl, phenol, and potassium chromate and dichromate. No significant differences in toxicity due to size were noted.

Bio-assays by Neil (162) indicated that for brook trout the 48-hr TL_m for KCN was approximately 0.09 mg/l. However, 0.1 of this concentration, or 0.009 mg/l, will reduce the ability of brook trout to swim against a current by about 50 per cent. Toxicity curves for CN were established by Burdick *et al.* (46) for brown trout and smallmouth bass at 60 and 70°F, respectively, through plotting mean time to death against concentration. The threshold value for brown trout implied in the curvature of the data appeared to be about 0.09 mg/l CN at 60°F and DO levels at or near saturation. Under the same DO conditions but at 70°F, the threshold for smallmouth bass appeared to be 0.104 mg/l CN. Lowering the DO level lowered the threshold value.

Bio-assays by Henderson *et al.* (100) have shown that while synthetic detergents and soaps are of nearly equal toxicity to fish in soft water, the former are approximately 40 times as toxic as soap in hard water. Alkyl benzene sulfonates are toxic to fish and are mainly responsible for the toxic properties of household syndets (detergents). The 96-hr TL_m values for fathead minnows averaged 6.6 mg/l (range 3.6 to 9.2 mg/l) in soft water and 4.3 mg/l (range 3.5 to 5.1 mg/l) in hard water for 4 ABS compounds frequently used in household syndets. On the basis of these experiments concentrations of ABS exceeding 1 or 2 mg/l may be expected to have some effect on the more sensitive fishes and other aquatic organisms in natural waters.

Additional References

Adlung, K. G., "The Toxicity of Insecticidal and Acaricidal Agents to Fish." *Naturwissenschaften*, **44**, 471 (1957); *Water Poll. Abs.* (Brit.), **31**, 430 (1958).

Alderdice, D. F., and Worthington, M. E., "Toxicity of a DDT Forest Spray to Young Salmon." *Can. Fish Culturist*, **24**, 41 (1959).

Anon., "The Problem of Waste Waters from the Paper Industry in Finland." *Bull. World Health Org.*, **14**, 2; and **14**, 5 (1956); *Water Poll. Abs.* (Brit.), **32**, 27 (1959).

Anon., "The Toxicity of Chemicals on Fish. II. The Estimation of the Effectiveness of Insecticides on the Young Carp, *Cyprinus carpio* Linne." *Bull. Japanese Soc. Sci. Fish.*, **22**, 641 (1957); *Biol. Abs.*, **33**, 10, 36526 (1959).

Bandt, H. J., "Poisoned Waters." *Wasserwirtschaft* (Germany), **48**, 338 (1958); *Water Poll. Abs.* (Brit.), **32**, 179 (1959).

Bandt, H. J., "The Toxicity of Weed-Killers to Fish." *Z. Fisch.*, **6**, 121 (1957); *Water Poll. Abs.* (Brit.), **32**, 4, 743 (1959).

Bringmann, G., and Kuhn, R., "Water Toxicology Studies with Protozoans as Test Organisms." Bundesgesundheitsamt für Wasser-, Boden- und Lufthygiene (Berlin-Dahlem), *Gesundh.-Ing.*, **80**, 239 (1959); *Chem. Abs.*, **53**, 22, 22630 (1959).

Chanin, G., and Dempster, R. P., "A Complex Chemical Waste and Its Toxicity to Fish." *Ind. Wastes*, **3**, 155 (1958); *Pub. Health Eng. Abs.*, **39**, 6, 31 (1959).

Chanin, G., and Dempster, R. P., "Deadly Mix." *Chem. Eng. News*, **36**, 16, 70 (1958); *Water Poll. Abs.* (Brit.), **31**, 431 (1958).

Clemens, H. P., and Sneed, K. E., "Lethal Doses of Several Commercial Chemicals for Fingerling Channel Catfish." U. S. Fish and Wildlife Service Spec. Sci. Rpt., Fish No. 316 (1959).

Davidson, F. F., "Poisoning of Wild and Domestic Animals by a Toxic Waterbloom of *Nostoc rivulare* Kuetz." *Jour. Amer. Water Works Assn.*, **51**, 10, 1277 (Oct. 1959).

Fitzgerald, G. P., "Control of Growth of Algae with DMU (3-(p-chlorophenyl)-1: 1-dimethylurea)." *Trans. Wisconsin Acad. Sci., Arts, Letters*, **46**, 281 (1958); *Pub. Health Eng. Abs.*, **39**, 3, 35 (1959).

Friedland, S. A., and Rubleva, M. N., "The Determination of the Maximum Permissible Concentrations in Case of Simultaneous Pollution of Surface Waters with Several Substances." *Hyg. and Sanit.* (U.S.S.R.), **23**, 11, 12 (1958); *Water Poll. Abs.* (Brit.), **32**, 179 (1959).

George, J. L., "Effects on Fish and Wildlife of Chemical Treatments of Large Areas." *Jour. Forestry*, **57**, 250 (1959); *Wildlife Rev.*, **96**, 13 (1959).

Hisaoka, K. K., "The Effects of 2-acetylaminofluorene on the Embryonic Development of the Zebrafish. I. Morphological Studies." *Cancer Res.*, **18**, 527 (1958); *Biol. Abs.*, **33**, 1985 (1959).

Hisaoka, K. K., "The Effects of 2-acetylaminofluorene on the Embryonic Development of the Zebrafish. II. Histochemical Studies." *Cancer Res.*, **18**, 664 (1958); *Biol. Abs.*, **33**, 1986 (1959).

Hoffman, C. H., "The Truth About Chemical Controls." *Amer. Forests*, **64**, 11, 12 (1958); *Wildlife Rev.*, **94**, 12 (1959).

Hubault, E., "Pollution of Natural Waters. Chemical and Biological Methods and the Fish Test." *Bull. Soc. Sci. Nancy*, **16**, 22 (1957); *Chem. Abs.*, **52**, 14038 (1958).

Lawrence, J. M., "Methods for Controlling Aquatic Weeds in Fish Ponds with Emphasis on Use of Chemicals." Agric. Exp. Sta. Ala. Polytech. Inst., Progr. Rep. Ser. No. 69 (1958); *Water Poll. Abs.* (Brit.), **32**, 154 (1959).

Lewallen, L. L., "Toxicity of Several Organophosphorus Insecticides to *Gambusia affinis* (Baird and Girard) in Laboratory Tests." *Mosquito News*, **19**, 1, 1 (1959); *Pub. Health Eng. Abs.*, **39**, 9, 14 (1959).

Polonovski, M., and Lindenberg, A., "Narcotics and Toxicity to Fish." *Arch. int. Pharmacodyn.*, **90**, 71 (1952); *Water Poll. Abs.* (Brit.), **31**, 430 (1958).

Rosen, A. A., and Middleton, F. M., "Chlorinated Insecticides in Surface Waters." *Anal. Chem.*, **31**, 10, 1729 (1959).

Somers, E., "Fungitoxicity of Metal Ions." *Nature*, **184**, Supplement No. 7, 475 (1959).

Souther, R. H., and Alspaugh, T. A., "Textile Waste Treatment Studies." *Proc. 13th Ind. Waste Conf.*, Purdue Univ., Ext. Ser. **96**, 662 (1959).

Tang, Y. A., and Chen, T. P., "Control of Chironomid Larvae in Milkfish Ponds." Chinese-Amer. Joint Commission on Rural Reconstruction, Fisheries Series: No. 4, Taipei, Taiwan, China, 36 pp. (1959).

Tarzwell, C. M., "What Makes Fish Live—and Die?" *Wastes Eng.*, **30**, 8, 443 (1959).

Webb, F. E., "Aerial Chemical Control of Forest Insects with Reference to the Canadian Situation." *Can. Fish Culturist*, **24**, 3 (1959).

Westlake, D. F., "Water Pollution Research, 1958." *Nature*, **184**, 4698, 1542 (1958).

Wuhrmann, K., and Woker, H., "Poisoning of Aquatic Fauna by Waste Water Pollution." *Verh. Int. Ver. Limnol.* (Germany), **13**, 557 (1958); *Pub. Health Eng. Abs.*, **39**, 11, 24 (1959).

Zehnder, A., and Hughes, E. O., "The Anti-algal Activity of Acti-Dione." *Can. Jour. Microbiol.*, **4**, 399 (1958); *Pub. Health Eng. Abs.*, **39**, 3, 39 (1959).

Organic Wastes

Effects of Organic Enrichment

A study of the effects of San Diego sewage on the growth and condition of young kelp plants indicated damage to the kelp (59). Manometric techniques used to measure the respiration of the kelp indicated a 60 to 80 per cent reduction after exposure to the sewage for 3 days. Centrifugation of the effluent did not eliminate toxic action (59). Newell (163) reports that the effects of the pollution of estuaries on the aquatic fauna may be much more complex than it is in rivers. Many estuarine animals such as polychaete worms can grow well in water which contains 0.2 of the saturation value of oxygen. Further, the presence of organic matter and of increased concentrations of PO_4 and NO_3 favors the growth of phytoplankton; and bottom deposits may be more favorable to burrowing animals than are clean sands. Toxic materials are deleterious even when greatly diluted.

According to Scott (194), the biological balance in streams differs from the concept as it is applied to lakes. It is not based on a balance of energy or elements but on the relative abundance of the various organisms composing the communities within the stream. It is suggested that in streams the term "balance" should be replaced by "biological diversity." The bottom fauna of New Zealand streams was studied by Hirsch (104) with the objective of devising biological criteria for evaluating the extent and severity of organic pollution. The biota found in stony bottomed streams shows characteristic reactions to pollution. In grossly polluted areas the fauna is composed of tubificid and niad worms and certain chironomid larvae. The other zones were similar to those described for North America.

Barnard (29) reports that the flocculent detritus in the harbors of Los Angeles and Long Beach, California, much of which is caused by domestic and industrial pollution, can be used as food by amphipods and polychaetes. The immersion of fresh surfaces indicated that the amphipods and polychaetes were consistently the earliest and most abundant settling metazoans in the harbor.

Laboratory experiments demonstrated that algae accelerate purification of organic wastes as indicated by the early termination of the anaerobic phase, the appearance of DO, and the acceleration of nitrification (216). The *B. coli* die-off was also accelerated. When *Chironomus riparius* were introduced into activated sludge which had been allowed to settle and consolidate for 6 months, they caused the pH value of the sludge to rise and increased the oxidation-reduction potential (74). Their effect on the overlying water was to increase the pH value and the concentration of NH_3 and to reduce the concentration of oxidized nitrogen.

An investigation was made by Allan *et al.* (11) into the condition of fish living in the effluent of a large sewage treatment plant. Large numbers of fish were caught in the effluent canal during summer but few were taken in winter. Similar fluctuations were noted in a nearby stream. There were some fish kills in the mile-long effluent canal and investigations were made to determine at what levels the various factors measured in the effluent (DO, pH, NH_3, temperature, CO_2, and heavy metals) become detrimental to the rainbow trout and other species. This was done by means of cage tests. It was found that the results of these tests agreed well with those determined in the laboratory. The data suggested that the lethal conditions which occurred in the effluent were due mainly

to low DO. The free CO_2 appreciably increased the sensitivity of the fish to the low oxygen. But for the presence of CO_2 which reduced the pH value of the effluent, the concentrations of NH_3 which were often present would have been toxic within a short period. The concentrations of metallic salts present were too low to kill fish rapidly when the O_2 concentration was high but they probably increased the susceptibility of the fish to the low DO.

The role of sewage plant effluents in the stimulation of algal growths in streams is discussed by Bucksteeg (45). Experiments are described on the use of *Scenedesmus obliquus* for the removal of enriching materials from wastewaters which have already received physical treatment. These algae were then removed from the water by chemical coagulation. A substantial purification of the water was attained in 24 hr. If unicellular algae were replaced with filamentous algae, these latter could be removed from the water by simple mechanical means.

Indicators of Organic Enrichment

In order to understand the manner in which the benthic fauna of the San Francisco Bay estuary responds to various pollutional conditions, the data from 312 collecting stations were examined by Filice (81). There was a total of 154 stations in what was considered normal areas. (It is doubtful if any unpolluted areas exist). A total of 39 species were taken in this area with an average of 6.5 species in each 10 liters of bottom materials. In the vicinity of industrial outfalls, 8 stations were established from which 3 species were taken at an average of 1 species/10 liters of substrate. In areas marginal to industrial outfalls, 39 stations were sampled at which 12 species were taken at an average of 3 species/10 liters of substrate. At domestic outfalls 13 stations were sampled which yielded 5 species and an average of 2 species/10 liters of substrate. There were 98 stations in areas marginal to domestic outfalls from which 30 species were taken at an average of 11.5 species/10 liters of substrate. These results indicate qualitative and quantitative changes in the benthic biota due to the addition of wastes.

When the Rio de la Plata enters an artificial lake the plankton population is drastically changed (130). The plankton population in the river is about 1,000 individuals per ml whereas in the reservoir it is 30,000/ml. While *Melosira, Coscinodiscus,* and *Nitzschia* are common in the river they do not prosper in the lake. Quantitatively the diatoms predominate in the river while in the lake Chlorophyceae and Cyanophyceae are dominant. In the lake blooms of *Anabaena, Anabaenopsis, Mougeotia, Geminella, Synedra,* and *Bumilleria* evolve rapidly in 4 to 7 days.

Additional References

Alfimov, N. N., and Mironov, O. G., "The Effect of Diatomaceous Plankton of Rivers on Certain Chemical Indices of Water Contamination." *Botan. Jour.* (U.S.S.R.), **43**, 1763 (1958).

Bick, H., "Contribution to the Ecology of Some Ciliates in the Saprobic System." *Vom Wasser*, **24**, 224 (1957); *Water Poll. Abs.* (Brit.), **32**, 14 (1959).

Cornelson, D., Sechter, I., Zamfir, H., Tudoranu, H., Birzu, A., and Feller, H., "Micro-Organisms Oxidizing Oil as Index for Stream Pollution with Petroleum Wastes." *Rev. Med.—Chir.*, **61**, 659 (1957); *Pub. Health Eng. Abs.*, **39**, 7, 27 (1959).

Emeis, C. C., "The Importance of Algae in the Biological Purification of Surface Waters." *Desinfekt. u. Gesundheitswes.*, **47**, 153 (1955); *Water Poll. Abs.* (Brit.), **31**, 396 (1958).

Hynes, H. B. N., "The Biological Effects of Water Pollution." Symposium on Effects of Pollution on Living Material, Inst. of Biology, London, Sept. 1958; *Water Poll. Abs.* (Brit.), **32**, 2, 71 (1959).

Izyurova, A. I., "Concerning the Possibility of Using Biological Methods for the Final Purification of Effluents Containing Petroleum Products." *Gigiena i San.* (U.S.S.R.), **2**, 72 (1958); *Pub. Health Eng. Abs.*, **39**, 11, 25 (1959).

Laird, M., "Parasites of Singapore Mosquitoes, with Particular Reference to the

Significance of Larval Epibionts as an Index of Habitat Pollution." *Ecology*, **40**, 2, 206 (1959).

Pentelow, F. T. K., Allan, I. R. H., Herbert, D. W. M., and Alabaster, J. S., "Sewage Effluents and Their Effect on Fish." *Surveyor* (Brit.), **116**, 986 (1957); *Sport Fishery Abs.*, **3**, 158 (1958).

Westlake, D. F., "The Effects of Biological Communities on Conditions in Polluted Streams." Symposium on Effects of Pollution on Living Material, Inst. of Biology, London, Sept. 1958; *Water Poll. Abs.* (Brit.), **32**, 2, 71 (1959).

Radioactive Wastes

Experiments were conducted on year old scaly and smooth carp to determine the uptake of P^{32} added to the water in Na_3PO_4 in amounts of 0.1 to 0.005 mg/l P^{32} and 20 to 200 μc/l (199). The highest P^{32} concentration was found in the scales and the lowest in the bones and kidneys. Absorption of inorganic P^{32} occurs in all parts of the intestine but is greatest in the anterior portion.

An investigation by Lebedeva (136) of the accumulation of radioactive strontium by *Daphnia magna, Diaptomus amblyoden*, and *Scenedesmus quadricauda* from water with Sr^{90} concentrations within the range of 2.7×10^{-12} to 3.4×10^{-4} c/l demonstrated that *Daphnia* accumulated much more than the other 2 organisms. *Daphnia* can take up considerable radioactivity within the first 5 minutes and can be used as specific indicators of radioactive contamination. Since aquatic organisms such as plankton, aquatic plants, molluscs, fish, and ducks accumulate significant amounts of radioactive Sr in their tissues from water and since the flesh of several of these is eaten, it is suggested that the maximum permissible concentration of radioactive strontium in reservoirs should be revised (150). Rice and Willis (184) report that with the possibility of increased contamination of the oceans with fission products there is need for determination of the uptake, accumulation, and loss of individual radionuclides by marine organisms. A culture of *Nitzschia closterium* containing dividing cells removed all the Ce^{144} originally added to the medium. Different species of algae concentrate Ce from 300 to 3,000 times over amounts in the medium in a period of 30 minutes. After 24 hr all 6 species tested had concentrated Ce from about 2,000 to 4,500 times. The amount of Ce taken up by *Nitzschia* cells increased as the concentration of Ce increased. Particulate Ce became associated with the cells at a faster rate than ionic Ce.

Experiments carried out in Russia (3) to learn the distribution of radioactivity in living and nonliving components of reservoirs demonstrated that Sr, Ru, and Ce were taken up by organisms while Cs was absorbed more strongly by soil and sand. When 4 species of fish were held in water containing radioactive Sr^{90} it was found that appreciable amounts of Sr^{90} were taken up over prolonged periods and that there was a direct relation between the concentration of Sr^{90} in the tissues and the activity in the water and the period of exposure (188). The uptake of Sr was inversely proportional to the concentration of Ca in the water. The largest amounts of Sr were concentrated in the scales and bones. Rosenthal (185) found that tissues containing high concentrations of Ca accumulate more Sr^{90} than do soft tissues. The rate of turnover of the nuclide varies from very fast to very slow according to the type of tissue. The whole body, head, and spine retain Sr^{90} for long periods while viscera lose the isotopes rapidly when the fish is transferred to fresh water. The nuclides formerly found in contaminated fish are Sr^{89}, Sr^{90}, Y^{90}, P^{32}, Cs^{137}, and Ru^{106} in bones and scales, Cs^{137}, Ru^{106}, Ce^{144}, Pr^{144}, Zr^{95}, and Nb^{95} in viscera and muscle (14). Others more recently found are Zn^{65}, $Cd^{113m-115}$, Fe^{55-59}, Mn^{54}, Ba^{140}, and La^{140} in viscera

and muscles (158). It has been found that aquatic organisms accumulate Cs^{137} (14).

Studies were made by Lackey (133) to determine the adsorption and absorption of radioactive isotopes on muck, sand, clay, fuller's earth, and silt. Cesium and Fe are usually most readily removed by adsorption. However, the exceptions are muck and silt which most readily removed U. Silica sand has less ion exchange capacity than fuller's earth. The settling out of turbidity removes some radioactivity.

Additional References

Chipman, W. A., "Disposal of Radioactive Materials and Its Relation to Fisheries." *Proc. Natl. Shellfisheries Assn.*, **49** (1959).

Rosenthal, H. L., "Comparative Uptake of Calcium-45 and Strontium-90 by Wild and Lordotic Guppies." *Proc. Soc. Exptl. Biol. and Med.*, **97**, 624 (1958); *Sport Fish. Abs.*, **4**, 1, 19 (1959).

Microbiology

Only four outbreaks (69) of enteric disease (445 cases) were attributed to contaminated water in 1958. This is the same number of outbreaks but represents about a seven-fold increase of cases over 1957. One occurrence of shigellosis followed failure to chlorinate the public water supply of a small city for several days and another of shigellosis occurred in a group of campers who drank inadequately treated water from a livestock watering tank. One outbreak of salmonellosis resulted from the use of a polluted well and one of gastroenteritis was due to contamination of a public water supply. Three boys became ill with typhoid fever after swimming in a stream which carried untreated sewage. The etiological organism was phage type E1.

Zhumatov and Dardik (237) described a large outbreak of infectious hepatitis among a rural population during the period of late summer field work. The disease appeared simultaneously in 44 communities and was caused by the use of water from an irrigation canal. Weber (223) discussed the use of chemical and bacteriological tests of ground water during an epidemic of infectious hepatitis. Sewage from 80 persons was treated mechanically and stored in seepage pits. Wells in the neighborhood were examined before seepage began; some were found to be faulty in construction, bacteriological results were sometimes unsatisfactory, but chemically there was no evidence of serious pollution. Examination six months after seepage began showed definite deterioration in the chemical quality of the water. Epidemic hepatitis broke out in two houses using these well waters.

In a study of the relationship of viruses and illnesses in a boys' summer camp, Paffenbarger *et al.* (172) concluded that the risks of contracting illness were not increased by exposure to swimming pool water and other communal objects. Clarke and Chang (56) reviewed the literature relative to enteric viruses in water. They found that despite the fact that all enteric viruses are feces borne and are sometimes present in sewage effluents, no enteric-virus disease other than infectious hepatitis has been shown to be water-borne, although a few outbreaks of poliomyelitis are suspect.

Welsh *et al.* (226) recovered *Coxiella burnettii* from the soil and surface water of premises harboring infected sheep in Solano County, California. Of the 19 water samples collected over a six-weeks period during the rainy season, 6 (32 per cent) contained *C. burnettii* in detectable amounts. Satisfactory results in the examination of naturally infected water samples with *Salmonella typhi* were obtained by Pandelescu and Rosu (174) by flocculating the water with 15-per cent solution of alum, settling 4 hr, redissolving the floc in phosphate buffer (pH 7.4) and inoculating on Wilson-Blair me-

dium. Cooke and Bartsch (60) isolated a number of relatively common aquatic fungi from streams that received domestic sewage and industrial wastes, but results indicated that additional information gained had little value in determining the degree of pollution of the stream. Chang *et al.* (51) reported the persistent occurrence of the nematode, *Diplogaster nudicapitatus*, in a city water supply using Ohio River water as a raw source. From the evidence available, it was believed that the raw river water was the source of infestation.

Leclerc (137) isolated bacteriophages active against Vi strains of *S. typhi* from 41.8 per cent of 430 samples of river water and 30 samples of lake and stagnant pool water in Hanoi (N. Vietnam). These phages could be subdivided into four groups according to plaque size and specificity of action. The value of the test for Vi-phage content in tracing sources of infection such as typhoid carriers was emphasized by Sturdza and Pandelescu (206). Polluting discharges increased the content of bacteriophage, and dilution by pure tributaries or by rain decreased it. The content of phage was affected by self-purification in the same way as the *Coli* titer and bacterial count but did not appear to play any part in the reduction of bacterial numbers. However, Zieminska (238), in comparing the presence of bacteria of the *E. coli* group and bacteriophages of some pathogenic intestinal bacteria in river water, observed no correlation between the *E. coli* titer and the titer of any of the phages isolated. He concluded that determination of the phage titer was not a suitable procedure for routine water examination.

When Thomas *et al.* (212) identified the coli-aerogenes bacteria in farm water supplies, they found that 37° negative strains of *Citrobacter freundii I* and *Klebsiella cloacae* were the main coli-aerogenes organisms recovered from high sanitary quality waters of springs and wells, but the coli-aerogenes microflora of polluted water was dominated by *E. coli I*, which comprised 43 per cent of the isolates at 30°C and 76 per cent of those at 37°C. Habs and Langeloh (93) investigated the significance of the so-called atypical coliform bacteria in water and concluded that the presence of atypical *E. coli* (*C. freundii*) was not precisely an indicator of fecal contamination, but rather implied that insufficiently filtered surface water had gained access to the source, and that the water was objectionable for this reason. Because coliform densities as determined in areas with different rates of enteric disease may not be comparable as measures of contamination, Christovao (55) proposed a "corrected" coliform index. The proposed corrective formula was considered as only a preliminary approximation. Gray (90) recommended a chemically defined medium containing formate, lactose, and glutomate, as a possible substitute for MacConkey broth in the presumptive coliform examination of water and Etinger-Tulczynska (79) pointed out that large numbers of various water bacteria may adversely affect the growth of *E. coli I* in MacConkey's broth at 37° and 42°C.

Guthof and Dammann (92) described a two-stage method for the cultivation of enterococci which was easy to perform. They believed it to be of particular value in assessing the significance of coliform counts. The search for enterococci in water, according to Graziadei-Celoria (91), was not only a necessary adjunct of tests for fecal contamination by coliforms and *Clostridia*, but essential for the judgment of water potability, especially if *E. coli* was not found among the coliforms present. Croft (64) compared the efficiency of media for the enumeration of enterococci in water and found that azide dextrose-ethyl violet azide and M-enterococcus agars showed the same order of productivity.

As recommended by Schiavone and

Passerini (189) the search for *Pseudomonas aeruginosa* should be included as a routine test in the bacteriological examination of drinking water because the inhibitory influence of *Pseudomonas* on the coliform group might otherwise lead to errors. Another source of error in streptococcal assays has been attributed to a bacterial inhibitor in distilled water by Price and Gare (176). The inhibition was caused by traces of short-chain fatty acids which could be removed by passing the water through a mixed bed ion exchange column or through activated charcoal. Mikhalyuk (155) observed varying results in the bacteriological examination of water depending on elapsed time and condition of transport of samples. Changes in bacterial content varied with initial number and kind of bacteria present as well as with the time and temperature of transport. Noble and Reitman (165) recovered about 25 per cent fewer colonies from a pure *E. coli* suspension on EHC Endo medium than on the same medium without fuchsin and sulfite. They, therefore, believed that in waters of low coliform content the membrane filter test using EHC medium might yield false negative results. Levin *et al.* (139) presented results using a sodium formate medium in the rapid, radioactive test for coliform organisms. They reported a reasonable degree of correlation between evolved $C^{14}O_2$ and number of cells. Some organisms produced gas by the isotope method but produced no gas in standard methods tube test. Metzler (154) discussed the reuse of treated wastewater for domestic purposes. He stated that an adequate water treatment plant could possibly remove pathogenic contaminants, but the reuse of sewage effluent for drinking purposes could be seriously hindered by chemical as well as by biological contaminants.

Henderson (102) used the membrane filter procedure for the estimation of coliform densities in sea water. He concluded that like any other procedure, the method has limitations and must be applied properly, but the method had advantages over the fermentation tube method by virtue of the labor, time, and materials saving, and that the precision of the membrane filter count was superior to that of the most probable number derived from fermentation tube results. Among the factors affecting the survival of bacteria in sea water reviewed by Carlucci and Pramer (49) were dilution, adsorption, sedimentation, hydrostatic pressure, solar radiation, temperature, pH, salinity, oxidation-reduction potentials, nutritive materials available, predators, bacteriophages, and other varied biological reactions.

Milbauer and Grossowicz (156) (157) claimed to have "reactivated" chlorine-treated *E. coli* by planting in protein-rich media. Planting such chlorine-treated cells in relatively weak media markedly reduced the number of "survivors." Brazis *et al.* (41) showed that inactivation of *Clostridium botulinum* toxins occurred as long as a free available chlorine residual remained in the water. Chloramines were relatively ineffective in destroying botulinum toxins. Laubusch (134) summarized the available information on the effectiveness of chlorine treatment in relation to various pathogenic bacteria, parasites, fungi, and viruses. To insure disinfection with chlorine, it was necessary to effect a suitable combination of available chlorine, contact time, and temperature as demonstrated locally by experiment and experience.

Disinfection of drinking water by the combined action of ultrasonic waves and small doses of disinfectants was studied by Elipiner (77). It was found that in the presence of small amounts of chlorine or hydrogen peroxide, disinfection was attained with much shorter periods of exposure to ultrasonic waves. DeLaney (71) evaluated a silver process for purifying water. The process failed to yield a

water that consistently met the bacteriological standards of the Public Health Service while operating within the limitations prescribed for the unit. Black *et al.* (37) found iodine to be a satisfactory disinfectant for swimming pool water. They reported no objectionable tastes and odors or eye irritations.

Chemistry

Interesting reports on the behavior of inorganic pollutants have appeared in the last year. Becking *et al.* (33) developed information on the formation of perchlorate in sea water. Kuhl and Mann (129) are responsible for detailed studies of the behavior of inorganic nitrogen compounds in a river estuary. The oxidation of nitrogenous material is also related to plankton populations and to numerous physical variables. Engelbrecht and Morgan (78) have made detailed studies of the occurrence and degradation of condensed phosphates in surface waters.

The chemical and physical behavior of "ABS" continues to require attention. Renn and Barada (183) investigated adsorption of ABS by a number of materials. Activated carbon was found far superior to all other agents investigated. Even with activated carbon, relatively large doses were required to remove nominal amounts of ABS. Oldham (170) found Lissapol-N to be well tolerated by a trickling filter in concentrations up to 50 mg/l. He reported about 30 per cent removed by adsorption, the rest passing through the filter. Truesdale (213) evaluated a number of factors in relationship to the foaming of aerated liquids containing various synthetic surface-active agents.

The biological degradation of specific materials has received further investigation. Styrene and isoprene were given laboratory investigation by Harkness and Jenkins (94) who found styrene to be subject to slow stabilization with isoprene being more resistant. Nasarenko (160) studied acetone and methanol and attempted to estimate stream tolerance of the chemicals. Bogan (38) notes that metabolic fragments of pollutants preclude analysis of stream effects in terms of pollutants originally introduced.

A pattern of combined studies of toxicity to mammals, taste, and odor determination and assay of stream behavior to reach an estimate of a tolerance is becoming evident abroad. A maximum permissible concentration for pyridine of 0.25 mg/l is suggested on the basis of toxicological studies and odor considerations (239). Fridlyand and Rubleva (83) considered the additive effect of odorous materials and the additive effects of metals on impairment of BOD oxidation. Benzene was considered in terms of taste and odor and a limit of 4.5 mg/l in reservoirs adopted (25). In terms of investigations of odor and physiological activity, isoprene and dimethyldioxane were examined (124). Limits of .005 mg/l for both substances were suggested.

Knorr (126) considered general aspects of petroleum production as a source of pollution. The prejudicial actions of petroleum derivatives, especially the carcinogenic power, are well known, and protection rules are discussed.

Steen (202) re-examined the solubility of oxygen in water, and he confirmed the values of Fox and Winkler as being correct to ± 1 per cent.

The interaction of phosphate and lake sediments has been further investigated by Olsen (171) and MacPherson *et al.* (148).

Additional References

Faifer, F. I., "Effect of Methanol on Water Organisms and Biochemical Processes of Self-Purification of Water." *Referat. Zhur., Khim, Abs.*, 31726 (1957); *Chem. Abs.*, **53**, 22, 22635 (1959).

Grin, N. V., "The Effect of Synthetic Fatty Acids on the Sanitary Regimen of a Reservoir." *Hyg. and Sanit.* (U.S.S.R.), **23**,

12, 13 (1958); *Water Poll. Abs.* (Brit.), **32**, 7 (1959).

Klein, L., "Chemical Aspects of River Pollution." *Research* (Brit.), **11**, 214 (1958); *Chem. Abs.*, **53**, 14, 13462 (1959).

Solomon, I., Cioara-Copolovici, E., and Sternhell, H., "Variations in the Biochemical Consumption of Oxygen Produced by Some Organic and Mineral Substances." *Igiena* (Hungary), **6**, 72 (1957); *Chem. Abs.*, **53**, 12, 11727 (1959).

Oxygen Sag and Stream Self-Purification

A comprehensive discussion of the effects of river impoundments on dissolved oxygen resources has been presented by Kittrell (123) with discussions by Jones and Ingols. The effects of relatively long- and short-term retention reservoirs are discussed, as is their importance in reducing the dissolved oxygen resources of the stream. In storage reservoirs having relatively long retentions the epilimnion may be saturated with dissolved oxygen while the hypolimnion oxygen resource is depleted by organic decomposition and lack of reaeration. Main stream reservoirs having smaller retention periods have reaeration and oxygen resource characteristics intermediate between those of an uncontrolled stream and the epilimnion of a storage reservoir.

Methods that may be used to overcome the dissolved oxygen depletions that occur with reservoirs are discussed and include multilevel penstock intakes, high-level penstock weirs, tailrace design, compressed air reaeration, and circulation by pumping.

Mercier (153) has also discussed the natural and artificial aeration of lakes, and summarizes such work for Lake Bret and Lake Morat, Switzerland. Details such as degree of pollution, location of the hypolimnion, and its oxygen concentrations are given. An aeration scheme is presented in which water would be withdrawn at two locations, aerated, and returned at a deep location, the two treatment units being located so as to cause circulation in the lake. Such treatment is needed from the end of May to early December, and water would be treated at a rate of 2 cu m/sec.

Laboratory investigations of the effects of domestic sewage on reaeration rates have been reported by Rand (178), who indicates that domestic sewage depressed the reaeration rate by a maximum of 60 per cent (undiluted sewage). The solubility of oxygen in sewage was found to be not significantly different from that in pure water, and the relative effect of sewage concentration was not dependent on degree of turbulence or mixing.

Studies of the mechanics of air entrainment for self-aerated flows in open channels have been made by Straub and Anderson (203) who indicate that air distribution is described by relationships based on a simplified view of turbulent transport, and that the maximum depth and mean velocity increase beyond those of a corresponding nonaerated flow.

Further experimental channel studies of the effects of detergents, settled sewage, and effluents on reaeration of waters of variable salinity have been reported by Ogden *et al.* (167). These authors conclude that "the lowering of the rate of aeration in saline water is quite pronounced but the proportional reductions produced by other factors do not appear to be dependent, to any great extent, on the presence of salt water." Gameson and Truesdale (85) have reported on field experiments to determine reaeration rates by use of a sodium sulfite method of deaeration. Gameson and Griffith (84) have also reported the results of a six month experiment with an automatic dissolved oxygen recorder on a polluted stream. The hourly and daily variations of DO are discussed and estimates of the best sampling times presented.

Additional References

Buscemi, P. A., "Littoral Oxygen Depletion Produced by a Cover of *Elodea canadensis*." *Oikos* (Denmark), **9**, 239 (1958).

Gameson, A. L. H., Vandyke, K. G., and Ogden, C. G., "The Effect of Temperature on Aeration at Weirs." *Water and Water Eng.* (Brit.), **62**, 489 (1958).

Hermann, E. R., "A Toxicity Index for Industrial Wastes." *Ind. Eng. Chem.*, **51**, 4, 84A (1959).

Pöpel, F., "Effect of Storm Water on the Sewerage System and the Receiving Stream." *Kommunalwirtsch.* (Germany), **9**, 340 (1957); *Zbl. Bakt., I, Ref.* (Germany), **167**, 544 (1958).

Voith, J. M., "Method and Apparatus for Aeration of Streams and for Promoting Self-purification Therein." *Chim. & Ind.* (France), **80**, 450 (1958).

Stream Studies and Surveys

There appears to be a distinct trend this year toward broadening the scope of stream investigations. Lakes, tidal reaches, and estuaries, as receivers of wastes, are being studied more intensively. Studies reported from numerous countries reflect the significance of stream pollution on water resource conservation on a worldwide basis.

The Public Health Service (22) issued a progress report of the first year's operation of the national water quality network. The results of the cooperative federal, state, and local effort fill a void long felt by water resource planners. Current research (21) on the monitoring of wastes in streams emphasizes the importance of bacterial indicators and protozoan, metazoan organisms, and the significance of organic contaminants.

ORSANCO (20) is trying out "robot monitors" that automatically record changes in water quality and that transmit information to the headquarters office. A prototype designed to measure chloride, specific conductance, temperature, pH, oxidation-reduction potential, and dissolved oxygen is under construction. Success in these efforts will reduce the drudgery and costs of field surveys. The Texas Health Bulletin (19) reports on "Stream Detectives," a joint effort of the Game and Fish Commission and Water Pollution Control Division of the Health Department. Sampling was carried on at 268 stations for the collection of data on specific conductance, total solids, chloride, sulfate, chlorine demand, and BOD. Illustrated descriptions of a number of electrical appliances for measuring and recording the condition of river water and discharge of trade wastewaters in Germany are given by Schuh (193). Instruments for recording salt content, pH, flow, and radioactivity and the design of recording apparatus and use of automatic telephones are described.

Hurwitz and Barnett (107) present a history of pollution control of the Chicago River from the early dilution projects of improving the drainage basin and diverting Lake Michigan water, to the treatment of virtually all wastes. Even with a high degree of treatment, the dissolved oxygen picture is not favorable with the established limit of 1,500 cfs diversion from Lake Michigan; greater diversion is required especially during warm weather periods.

Bartsch and Ingram (30) developed an excellent summary on the effects of a hypothetical domestic sewage load on various chemical, physical, and biological factors in a stream; colored plates are used. The effects on BOD, dissolved oxygen, bacteria, and higher organisms are dealt with. Especially significant is the discussion of diurnal dissolved oxygen patterns and the zonation of organisms in distance as related to time of passage and natural self-purification.

As many rivers in England receive discharges of large volumes of cooling water, Gameson *et al.* (86) studied the variation in temperature of a stretch of the river Lea below a power station at Hoddesdon, Herts. Diurnal variations in temperature were so great that flow of water could be traced downstream for 5.5 miles. The rate of exchange of heat between water and its surroundings was estimated, the average coefficient being 2.6 cm/hr, or 5.4 Btu/hr/sq ft/°F excess temperature.

Based on a number of physical, chemical, and biological factors, pollution problems of 3 lakes and 5 streams in France were considered by Vivier (217). Depending on climatic and hydrographic factors, a chronic pollution problem can change quickly into an acute one even when treated municipal waste is the source of pollution. Chene (52) discusses the noxious biological effect of industrial wastewater in rivers, especially from the piscicultural point of view, with special attention to harmful substances in the liquid residue of paper manufacturing.

Floquet (82) reports on stream pollution control of a steel-producing region of Lorraine. The control system is based on scheduled analyses of intake water and plant effluents from top to bottom of the valley; 25 per cent reduction in pollution was achieved even during a period of sharp increase in factory output.

A paper by Jaag (113) describes some of the pollution problems of the Reuss River watershed in Switzerland based largely on biological, physical, and chemical data gathered from a number of tributaries and lakes in the area. Heide and Thiele (99) studied the boron content of the River Saale; comparative data are given for concentrations of boron in different rocks, Saale water, and sea water. A study (18) of the Rhine River over a 24-hr period is detailed. An account is given of the various laboratories taking part and of co-ordination of methods of analysis. Results are discussed, compared to earlier investigations, and used in a detailed survey of the condition of the Rhine and its variations in the different sections. Schmassmann (192) discusses the meaning of and the conclusions to be drawn from the results of the previous study.

Yurgenson (234) studied the sanitary condition of wastewaters of a bituminous chemical plant and their effects on the rivers Erra and Purtse in order to evaluate pollution in water reservoirs. Both rivers proved highly polluted, calling for radical sewage treatment prior to diversion of the river water to reservoirs. The sanitary characteristics of the Kama River, Russia, below waste discharges from an aniline dyeworks is reported by Kuper (131). To protect the downstream water supply, fecal wastes are to be treated separately or discharged to municipal sewerage, and process wastes are to be settled and released to achieve maximum mixing with the left bank current.

Okada and Uesugi (168) studied the industrial waste pollution of the rivers Ichi and Yumesaki, Japan. The Ichi receives wastes from various factories, a paper mill, and several tanneries, causing an increase in sulfates, organic substances, suspended solids, and a lowering in dissolved oxygen; the Yumesaki is polluted by wastes from a glue factory that increases the sulfate, chloride, and lime concentration of the river water.

Johannesson (115) conducted a survey of the Manawatu River in New Zealand. A typical dissolved oxygen sag was observed although minimum values were not critical and recovery complete. A pronounced photosynthetic contribution to re-oxygenation during daylight hours was observed.

Studies relating to pollution of marine waters are becoming more prominent in the literature of sanitary engineering and science. Glenn and Cowherd (88) explain the development and application of mathematical-graphical principles of sinusoidal variations of dissolved oxygen in tidal water throughout a tidal cycle. They demonstrate through sampling studies in New York Harbor that sinusoidal variations of tidal cycles are related to oxygen contents which can be predicted from extrapolated sine curves.

Yakovenko (233) in Russia, discusses the sanitary protection of marine waters near seaside towns. It is pointed out that the sanitary condition

of sea water varies, depending on currents, amount of rainfall, prevailing winds, and tides. The degree of pollution is shown by the indexes of oxidizability, ammonia content, phosphates, coli-index, contents of salts and chlorine, and the count of helminthic ova. A biological index of assessing pollution is based on the comparison of seaweed flora of polluted and non-polluted water. To adequately protect shore waters, there should be a systematic inclusion of all seashore establishments into a sewerage system with proper selection of the points of discharge, taking into consideration the tides and winds. Also, attention should be given to the proper disposal of wastes from ships. Epidemiological studies should be given great importance in assessing the effects of sewage pollution on the population that bathes in beach waters.

Shiyazuki and Hayama (200) discuss the pollution from a steel works at Kudamatsu, Japan. They note that Kasado Bay is affected up to 500 m from shore by 80 to 200 mg/l of phenol and up to 200 mg/l of ferrous sulfate. They further deal with phenols in the waste liquor from a coal-gas plant, noting that phenols can be removed by treatment with activated carbon. They state that the carbon can be regenerated with benzene.

Daniels *et al.* (67) report on a sanitary survey of marine waters at Ferndale, Washington, preparatory to initiating a refinery operation and a post-survey after plant operation had been initiated. Surveys include the sampling of fauna and flora, including plankton, bottom type, and determinations of water quality. Surveys revealed that waste treatment facilities were adequate to preserve conditions similar to those in the receiving water before plant operations were begun.

Rawn (180) describes the bacterial monitoring system and continuous analysis program employed by the Los Angeles County Sanitation Districts to protect coastal, offshore, and deep water recreational areas. The program consists of 3 phases which include:

1. Sampling and analyzing the effluent from the treatment installation.
2. Daily sampling and analysis of all shore stations near the outfall where substantial recreational use exists, as well as a staggered five-day weekly schedule of sampling at other shore stations.
3. Once weekly sampling of offshore water in the vicinity of the ocean outfall discharge area.

Analyses made on shore and offshore samples include DO, BOD, coliforms (MPN), and organic content. Monitoring of plant effluent includes daily analyses of BOD, suspended solids, pH, grease (ether extracted), and radioactivity.

Daily analyses of digested sewage sludge include: total solids, total volatile solids, pH, grease, and radioactivity.

Coxon (62) discusses the problem of present extensive pollution of the tidal reach of the River Tyne and emphasizes the deleterious effects of this pollution on human health and fish life. As a result of untreated domestic sewage pumped to the river from Tyneside, anaerobic conditions exist for 12 miles along its course. Remedial measures are recommended in either construction of a sewage treatment installation or by disposing of the sewage to sea; pros and cons of these alternate proposals are discussed.

Interest appears to be increasing in publication of pollution investigations of lakes. Ruffel (186) developed a method of calculation which can be applied to the dilution of sewage effluents in a reservoir. He substantiated his calculations with actual dilution rates that were determined analytically by field sampling.

Wilhelm (229) demonstrated the advantages of thermistors over Kipp thermometers in reporting stratifica-

tion data for Schliersee Lake. Field data revealed that the northern portion has a higher yearly average temperature than the southern part because of stronger mixing by the entry of tributaries. Data indicate that the lake which is divided by the island of Worth should be regarded hydrographically as well as morphologically as two basins. Dissolved oxygen determinations indicate that the northern part is the most heavily polluted. The effects of wind on isotherms are discussed.

Curl (66) investigated the origin and distribution of phosphate phosphorus in western Lake Erie which is shown, as a result of drift current patterns, to be related to discharges of the Maumee and Detroit Rivers. The bedrock in the lake provided negligible quantities. Respectively, 405 and 125 metric tons are provided by the Detroit and the Maumee Rivers. Soluble phosphorus, possibly as a precipitate of ferric phosphate and by adsorption onto ferric hydroxide, is lost. Thus, the bottom sediments were found to be considerably enriched in phosphorus. Phosphate phosphorus and turbidity were positively correlated, this turbidity sometimes preventing any significant phytoplankton growth. Removal of fish by man was estimated to account for an annual loss of 29 metric tons of phosphorus, or 6 per cent of the annual phosphorus input. About 94 metric tons, or approximately 20 per cent of the annual phosphorus input may be held temporarily in the standing phytoplankton.

Corbella *et al.* (61) report on the toxic effects of cupro-ammonia pollution on bottom fauna and algae from an artificial silk factory which discharges its effluents to Lake Orta, in northern Italy. The effects of pollution on the biota are confined to the top 6 cm of sediment. Here the elimination of benthic fauna resulting in a cessation of burrowing action has stopped the turnover of bottom mud. It was found that there was a fairly good relation between concentrations of copper, organic matter, and chlorophyll.

Stream Standards

Lovett (144) reviewed the history and present status and use of standards in England. The first report of the Rivers Pollution Commission, 1868, recommended "standards of purity" for effluents, which proposed limits for suspended organic and mineral matter, organic carbon, and nitrogen, sulfides, metals, other than the common alkaline earth metals, acidity, alkalinity, arsenic, free chlorine, oil, and color. The eighth report of the Royal Commission on Sewage Disposal, 1913, included a recommendation of a general standard for sewage effluents that would limit suspended matter to 30 mg/l and 5-day, 18.3°C, BOD to 20 mg/l. If dilution of effluent by the receiving stream was as great as 150 to 1 the BOD standard might be omitted, and the suspended matter limit increased to 60 mg/l. With a dilution as great as 500 to 1 crude sewage might be discharged. The same report included river water classification as shown in Table III. Most of these recommendations still are rather widely accepted. The desirable approach is not how much waste can be discharged to streams, but rather how much potentially polluting matter can be withheld from streams by reasonable and practicable methods. King (121) presented the general viewpoint of the chemical industry with regard to standards. The earlier standards had little reference or applicability to trade effluents. Gen-

TABLE III.—British River Water Classification in Terms of BOD

Classification	5-day BOD (mg/l)
Very clean	1
Clean	2
Fairly clean	3
Doubtful	5
Bad	10

eral effluent standards tend to impose excessively stringent and costly treatment requirements on industry. Flexible stream standards are preferable. Such standards should be based on careful stream surveys that establish the waste assimilative capacities of the stream sections involved. Much research is needed on methods of analysis, reactions of wastes in streams, industrial wastes characteristics, and methods of waste treatment. Standards should be based on adequate scientific data, reasonable for their purpose, and reasonably capable of economic attainment. The river boards have authority to adopt bylaw standards, but none has done so, which probably indicates that such an approach to pollution control is impracticable. The Pollution Prevention Sub-Committee of the Central Advisory Water Committee circular, 1954, recommended standards based on suspended solids, BOD, pH, and temperature, but rejected standards for organic carbon, toxicity to fish, color, repression of natural self-purification, and liquids immiscible in water.

Hollis and McCallum (106) reviewed the present status of water use and stream pollution in the United States and assessed the prospects for the future. They pointed to the ever-increasing reuse of water and to the rapidly expanding production of new chemicals, as well as the continuing growth of the more familiar sources of wastes and the lessening distances between sources, and concluded that dilution is no longer the solution for pollution. The traditional parameters of pollution—BOD, bacterial indicator organisms, and determinations of natural organic and inorganic substances, and of taste and odor—no longer can be relied on as the only measures of efficiency of waste treatment. Insecticides, pesticides, herbicides, synthetic detergents, new chemical fertilizers, antibiotics, radionuclides, and a host of other new and forthcoming chemicals demand new parameters for their evaluation and control. Development of these new parameters must be accompanied by advances in many of the other techniques involved in the protection of quality of the nation's available water resources.

The Court of Appeals recently ruled (23) that the New York State Water Pollution Control Board has the properly legislated power to set standards of purity for the state's waters, and to compel communities to maintain them, and that the Board should base its standards on scientific facts rather than on how much pollution abatement might cost any given community.

Maximum permissible limits for two organic compounds in water have been proposed by Russian scientists. Lisovskaya (142) recommends a limit of 0.02 mg/l for metaphos (dimethylparanitrophenylthiophosphate), and Zhakov (236) proposed a limit of 0.1 mg/l for Ursol D ($p\text{-}C_6H_4(NH_2)_2$) in reservoirs.

Abatement and Control

Reports from several sources during the year reflect the progress or lack of progress being made in the United States to abate pollution of principal waters.

In a recent interview Secretary Flemming stated that pollution of rivers is high on the list of Department of Health, Education, and Welfare projects (24). He discussed circumstances under which the government acts against cities or industries and stated that six basins are now getting special attention: Missouri, Potomac, Ohio, Delaware, Arkansas-Red, and the Columbia. McCallum (151) reviewed the details of the Federal Water Pollution Control Act of 1956 (PL 660). He stated that the primary responsibility for water pollution control rests with the states, with the Federal government in a supporting role. Technical assistance activities are being directed more and more to regional and

interstate problems rather than to problems of individual states.

Weber (222) discusses the work of the International Joint Commission (United States and Canada) concerning pollution of boundary waters. An international warning system for notifying downstream water users following industrial waste spills has been established. In Canada, the Ontario Water Resources Commission Act of 1957 granted the Commission power to supervise all water and sewage works projects in the Province and to provide aid in the financing and construction of these projects for municipalities and others (35). To date 40 municipalities have agreements with the Commission for projects totalling $25 million.

European problems in the protection of waters are presented in a report (73) of papers given at the International Congress of European Problems in the Protection of Waters, October 1956. The papers discuss measures taken to maintain the salubrity of Lake Constance, means of purifying the Danube (140), the protection against and effects of pollution of the Rhine (112), and protection of the Moselle and the Saar against water pollution (127). Several other waters are also discussed. Poehlmann (175) emphasizes the necessity for control of the condition of the Rhine with special reference to steps required in the iron industry. It is reported that the International Commission for the Protection of the Rhine against Pollution studies the water quality of the river and ways to improve it. It is hoped that the Commission, composed of Germany, France, Luxembourg, the Netherlands, and Switzerland, will develop a code to aid in improving water quality (235).

Pollution controls in the Longwy Basin (82) are carried out by cooperation of the Inter-Industry Pollution Commission, the Forest Service, the Bridges and Highway Service, and the rural sanitary engineer. Problems involved in the basin, in which a large concentration of steel mills, coke furnaces, and related industries are located, have been described.

Witzel (231) discusses the need for international legislation regarding the protection of international or boundary waters. One case is cited where civil action could have been taken by Germany when an accidental discharge of heavy oil from Austria damaged fish and bird life in Lake Constance and caused harm to bathing beaches and water supplies in Germany. Bucksch (44) discusses principles on which international legislation regarding waterways could be based. There is conflict between the territorial principle which gives complete rights to the state over waters within it, and the integrity principle which gives the state a right to ask that all waters entering it shall be in the pristine state. The coherence principle developed by Hartig is also cited. This considers the river area as one unit in which each state has complete freedom of use within its own boundaries provided the water is not affected beyond its boundaries.

Kirdorf (122) reviews the law of the Rhineland-Palatinate for the protection of waters (1956). Specific clauses are included relating to protective areas. Lohr (143) discusses the Bavarian Water Law and the authorities responsible for the protection of streams, treatment of sewage and industrial wastewaters, financial provisions, and present conditions of treatment and disposal of sewage.

LeClerc (138) states that in Belgium problems in protection of rivers against industrial pollution arise because of the concentration of industries in specific localities and the lack of water. Rivers are classified into those used for public water supply, fishing, and industrial waste discharge. Particular pollution problems associated with sugar refineries, iron and steel works, and linen mills are discussed.

References

1. Adlung, K. G., "Toxicity of Dinitrocarbazole to Fish." *Naturwissenschaften* (Germany), **45**, 631 (1958); *Water Poll. Abs.* (Brit.), **32**, 951 (1959).
2. Adlung, K. G., "The Toxicity of Insecticides to Fish and Its Dependence on Temperature." *Naturwissenschaften* (Germany), **44**, 622 (1957); *Water Poll. Abs.* (Brit.), **31**, 430 (1958).
3. Agafanov, B. M., "Some Experiments in Biological De-Activation of (Radioactive) Water. Laboratory Tests in Small Tanks." Trud. Vses. Konf. Med. Radiol., Vopr. Gig. Dozimetr., 79 (1957); *Water Poll. Abs.* (Brit.), **32**, 107 (1959).
4. Albersmeyer, W., and Erichsen, L., "Examination of the Effects of Tar Constituents in Waste. I. General Information of Waste with Special Consideration of the Phenols and Their Effects on Fish." *Zeits. fur Fischerei*, **8** (n.s.) (1–3), 29 (1959).
5. Albersmeyer, W., and Erichsen, L., "Examination of the Effects of Tar Constituents in Waste. II. Toxicity Test on Fish." *Zeits. fur Fischerei*, **8** (n.s.) (1–3), 36 (1959).
6. Albersmeyer, W., and Erichsen, L., "Examination of the Effects of Tar Constituents in Waste. III. On the Question of the Adverse Effects of Phenols in the Taste of the Fish with Particular Reference to the Uptake—Release Ratio." *Zeits. fur Fischerei*, **8** (n.s.) (1–3), 40 (1959).
7. Albersmeyer, W., and Erichsen, L., "Examination of the Effects of Tar Constituents in Waste. IV. On the Question of the Adverse Taste from Fish Due to Phenol-Containing Waste." *Zeits. fur Fischerei*, **8** (n.s.) (1–3), 44 (1959).
8. Albersmeyer, W., and Erichsen, L., "Examination of the Effects of Tar Constituents in Waste. V. The Damage to Fish Propagation Through the Action of Phenols." *Zeits. fur Fischerei*, **8** (n.s.) (1–3), 47 (1959).
9. Albersmeyer, W., "Examination of the Effects of Tar Constituents in Waste. VI. The Toxicity of Phenols, m-Cresol, and 1,4,5-Xylenol for Several Animals Consumed by Fish." *Zeits. fur Fischerei*, **8** (n.s.) (1–3), 50 (1959).
10. Albersmeyer, W., "Examination of the Effects of Tar Constituents in Waste. VII. The Effects of Phenols on Various Microorganisms." *Zeits. fur Fischerei*, **8** (n.s.) (1–3), 59 (1959).
11. Allan, I. R. H., Herbert, D. W. M., and Alabaster, J. S., "A Field and Laboratory Investigation of Fish in a Sewage Effluent." *Ministry Agr., Fisheries, and Food Fishery Invest.*, Ser. 1, **6**, 2, 1 (1958).
12. Anon., "Freshwater Biological Assn. 25th Annual Report for the Year Ended 31st March 1957." 70 pp. (1957); *Water Poll. Abs.* (Brit.), **32**, 44 (1959).
13. Anon., "Freshwater Biological Assn. 26th Annual Report for the Year Ended 31st March 1958." 86 pp. (1958); *Water Poll. Abs.* (Brit.), **32**, 7, 1205 (1959).
14. Anon., "Hanford Biology Research. Annual Report for 1957." Off. of Tech. Services, U. S. Dept. of Commerce, Washington, D. C. HW-53500, 228 pp. (1958).
15. Anon., "Toxicity Index Proposed." *Chem. Eng. News*, **36**, 52, 26 (1958); *Water Poll. Abs.* (Brit.), **32**, 179 (1959).
16. Anon., "The Ruhr. Repeated Destruction of Fish." Mitt. Ver. Deutsche Gewässerschutz., 11 (1958); *Water Poll. Abs.* (Brit.), **32**, 248, 1331 (1959).
17. Anon., "Investigations on Fure Lake 1950–54. Limnological Studies on Cultural Influences." Inst. Danish Civil Eng., Sew. Committee, Dansk. Ing-Foren. Spildevandskom. Publ. No. 11 (1958); Folia limnol. scand. No. 10, 190 pp. (1958); *Water Poll. Abs.* (Brit.), **32**, 7, 1215 (1959).
18. Anon., "Pollution of the Rhine from Lake Constance to Karlsruhe." Fachkommission fur Regionale Abwasserfragen der Regionalplanungsgruppe Nordwestschweiz. Rept. No. 3; Wasser u. Energiew., Nos. 5 and 10, 36 pp. (1957); *Water Poll. Abs.* (Brit.), **32**, 5, 942 (1959).
19. Anon., "Stream Detectives." *Texas Health Bulletin*, **12**, 3, 3 (1959).
20. Anon., "Robot 'Cops' on Ohio." *Chem. Week*, **24**, 85, 44 (1959).
21. Anon., "Research in Water Supply and Water Pollution at the Robert A. Taft Sanitary Engineering Center." U. S. Dept. of HEW, Pub. Health Serv. (Aug. 1, 1959).
22. Anon., "National Water Quality Network." U. S. Dept. of HEW, Pub. Health Serv. (1958).
23. Anon., "Court Upholds New York Pollution Control Board." *Wastes Eng.*, **30**, 638 (1959).
24. Anon., "HEW Renews War on River Wastes." *Chem. Eng. News*, **37**, 19, 40 (1959).

25. Avramenko, V. P., "Permissible Content of Benzene in the Water of a Reservoir." *Trudy Khar'kov. Med. Inst.* (U.S.S.R.), **35**, 182 (1955); *Referat. Zhur., Khim, Abs.*, 69291 (1956); *Chem. Abs.*, **53**, 22, 22629 (1959).

26. Bandt, H. J., "Toxic or Non-Toxic to Fish?" *Deutsche Fischerei Zeits.* (Germany), **4**, 170 (1957); *Water Poll. Abs.* (Brit.), **31**, 431 (1958).

27. Barber, F. G., "On the Dissolved Oxygen Content of the Waters of the Hecate Region, B. C." Progr. Rep. Biol. Stas. Nanaimo and Vancouver, 110, 3 (1958); *Water Poll. Abs.* (Brit.), **32**, 4, 636 (1959).

28. Barnhart, R. A., "Chemical Factors Affecting the Survival of Game Fish in a Western Colorado Reservoir." *Colorado Cooperative Fisheries Res. Unit Quarterly Rept.*, **4**, 25 (1958); *Sport Fish. Abs.*, **3**, 114 (1958).

29. Barnard, J. L., "Amphipod Crustaceans as Fouling Organisms in Los Angeles-Long Beach Harbours, with Reference to the Influence of Sea-Water Turbidity." *Calif. Fish Game*, **44**, 161 (1958).

30. Bartsch, A. F., and Ingram, W. M., "Stream Life and the Pollution Environment." *Pub. Works*, **90**, 7, 104 (1959).

31. Basu, S. P., "Active Respiration of Fish in Relation to Ambient Concentrations of Oxygen and Carbon Dioxide." *Jour. Fish. Res. Bd. of Canada*, **16**, 2, 175 (1959).

32. Beak, T. W., "Biological Survey of the St. Clair River." *Ind. Wastes*, **4**, 5, 107 (1959).

33. Becking, L. G. M. B., Haldane, A. D., and Izard, D., "Perchlorate, an Important Constituent of Sea Water." *Nature* (Brit.), **182**, 654 (1958); *Water Poll. Abs.* (Brit.), **32**, 4, 123 (1959).

34. Beneden, G. V., "The Effects of the Discharge of Sludge and of the Bottom Deposits on the Biological Equilibrium of Receiving Streams." *Bull. Centre Belge Etude et Document. Eaux* (Belgium), **36**, 99 (1957); *Water Poll. Abs.* (Brit.), **32**, 3, 550 (1959).

35. Berry, A. E., "The Ontario Water Resources Program." *Sewage and Industrial Wastes*, **31**, 3, 288 (Mar. 1959).

36. Birdsall, L. I., "Cleaning up the Rivers and Streams of Cook County, Illinois." *Proc. 13th Ind. Waste Conf.*, Purdue Univ., Ext. Ser. **96**, 3, 81 (1958).

37. Black, A. P., Lackey, J. B., and Lackey, E. W., "Effectiveness of Iodine for the Disinfection of Swimming Pool Water." *Amer. Jour. Pub. Health*, **49**, 8, 1060 (1959).

38. Bogan, R. H., "Biochemical Degradation Products—A New Dimension in Stream Pollution." *Proc. 12th Ind. Waste Conf.*, Purdue Univ., Ext. Ser. **94**, 317 (1957).

39. Boudreaux, J., Strawn, K., and Callas, G., "Fire Ants, Heptachlor, and Fish Kill." *Southwestern Nat.*, **3**, 7 (1959); *Biol. Abs.*, **34**, 4, 9500 (1959).

40. Boyd, J. E., "The Use of *Daphnia Magna* in the Microbioassay of Insecticides." *Dissertation Abs.*, **18**, 51 (1958); *Sport Fish. Abs.*, **3**, 87 (1958).

41. Brazis, A. R., Bryant, A. R., Leslie, J. E., Woodward, R. L., and Kabler, P. W., "Effectiveness of Halogens or Halogen Compounds in Detoxifying *Clostridium botulinum* Toxins." *Jour. Amer. Water Works Assn.*, **51**, 7, 902 (1959).

42. Brett, J. R., Hollands, M., and Alderdice, D. F., "The Effect of Temperature on the Cruising Speed of Young Sockeye and Coho Salmon." *Jour. Fish. Res. Bd. of Canada*, **15**, 4, 587 (1958); *Sport Fish. Abs.*, **4**, 1, 31 (1959).

43. Brett, J. R., "Some Principles in the Therman Requirements of Fishes." *Quart. Rev. Biol.*, **31**, 2, 75 (1956); *Biol. Abs.*, **33**, 8, 29575 (1959).

44. Bucksch, R., "Solution of International Legal Problems of River Protection According to the 'Coherence' Principle." *Österr. Wasser.* (Austria), **10**, 133 (1958); *Water Poll. Abs.* (Brit.), **32**, 5, 933 (1959).

45. Bucksteeg, W., "The Culture of Algae in Waste Waters to Prevent the Secondary Pollution of Watercourses." *Bull. Centre Belge Etude et Document. Eaux* (Belgium), **36**, 83 (1957); *Water Poll. Abs.* (Brit.), **32**, 97 (1959).

46. Burdick, G. E., Dean, H. J., and Harris, E. J., "Toxicity of Cyanide to Brown Trout and Smallmouth Bass." *N. Y. Fish and Game Jour.*, **5**, 133 (1958).

47. Burrows, R. E., "Light as a Factor in Accelerating the Spawning of Blueback Salmon." *Progr. Fish-Cult.*, **20**, 2, 57 (1958).

48. Cairns, J., Jr., and Scheier, A., "The Relationship of Bluegill Sunfish Body Size to Tolerance for Some Common Chemicals." *Proc. 13th Ind. Waste Conf.*, Purdue Univ., Ext. Ser. **96**, 3, 243 (1959).

49. Carlucci, A. F., and Pramer, D., "Factors Affecting the Survival of Bacteria in Sea Water." *Applied Microbiol.*, **7**, 6, 388 (1959).

50. Caspers, H., "Biological Investigations in Hamburg Harbour." *Fischwirt* (Germany), **7**, 281 (1957); *Water Poll. Abs.* (Brit.), **32**, 44 (1959).

51. Chang, S. L., Austin, J. H., Poston, H. W., and Woodward, R. L., "Occurrence of a Nematode Worm in a City Water Supply." *Jour. Amer. Water Works Assn.*, **51**, 5, 671 (1959).

52. Chene, M., "The Problems of the Discharge of Waste from Paper Mills in Rivers." *Rev. Path. Gen. Physiol. Clin.*, **57**, 689, 967 (1957); *Pub. Health Eng. Abs.*, **39**, 22 (1959).

53. Chipman, R. K., "Studies of Tolerance of Certain Freshwater Fishes to Brine Water from Oil Wells." *Ecology*, **40**, 299 (1959).

54. Choudhury, S. H., "An Investigation of the Karnaphuli Paper Mill Effluent and its Detrimental Effects on Fish and Other Aquatic Life of the River." *Agr. Pakist.*, **8**, 138 (1957); *Water Poll. Abs.* (Brit.), **31**, 385 (1958).

55. Christovao, D. A., "The Significance of the Coliform Index and a Proposal for a Corrected Index." *Arquivos Facul. de Hig. e Saude Publica*, Univ. de Sao Paulo (Brazil), **11**, 88 (1957); *Bull. Hyg.*, **33**, 967 (1958); *Pub. Health Eng. Abs.*, **39**, 7, 51 (1959).

56. Clarke, N. A., and Chang, S. L., "Enteric Viruses in Water." *Jour. Amer. Water Works Assn.*, **51**, 10, 1299 (1959).

57. Clemens, H. P., and Sneed, K. E., "Lethal Doses of Several Commercial Chemicals for Fingerling Channel Catfish." U. S. Fish and Wildlife Service Special Scientific Rept., 316 (1959).

58. Clendenning, K. A., "The Effects of Waste Discharges on Kelp." Univ. of Calif. Inst. of Marine Res. Quart. Progr. Rept. (Jan.–Mar. 1958).

59. Clendenning, K. A., "Toxic Action of Contaminated Sea Water Upon Young Kelp Plants." Univ. of Calif. Inst. of Marine Res. Quart. Progr. Rept. (Oct.–Dec. 1957).

60. Cooke, W. B., and Bartsch, A. F., "Aquatic Fungi in Water with High Waste Loads." *Sewage and Industrial Wastes*, **31**, 11, 1316 (Nov. 1959).

61. Corbella, C., Tonolli, V., and Tonolli, I., "Sediment in Lake Orta, the Sign of Severe Cupro-Ammoniacal Pollution." *Mem. Ist. Ital. Idrobiol. de Marchi* (Italy), **10**, 9 (1958); *Pub. Health Eng. Abs.*, **39**, 28 (1959).

62. Coxon, T. L. J., "River Pollution in Tidal Waters." *Contract. Rec.*, **69**, 29, 16 (1958); *Water Poll. Abs.* (Brit.), **32**, 3, 547 (1959).

63. Crandall, C. A., and Goodnight, C. J., "The Effect of Various Factors on the Toxicity of Sodium Pentachlorophenate to Fish." *Jour. Limn. and Ocean.*, **4**, 53 (1959).

64. Croft, C. C., "A Comparative Study of Media for Detection of Enterococci in Water." *Amer. Jour. Pub. Health*, **49**, 10, 1379 (1959).

65. Crouter, R. A., and Vernon, E. H., "Effects of Black-Headed Budworm Control on Salmon and Trout in British Columbia." *Canadian Fish Culturist*, **24**, 23 (1959).

66. Curl, H., Jr., "The Origin and Distribution of Phosphorus in Western Lake Erie." *Jour. Limn. and Ocean.*, **4**, 66 (1959); *Pub. Health Eng. Abs.*, **39**, 8, 30 (1959).

67. Daniels, E. K., Lutz, J. R., and Caster, L. A., "Pollution Control at Ferndale, Washington." *Proc. Amer. Petroleum Inst.*, Sec. III, Refining, **38**, 3, 282 (1958).

68. Darsie, R. F., and Corriden, F. E., "The Toxicity of Malathion to Killifish (Cyprodontidae) in Delaware." *Jour. Econ. Entomology*, **52**, 4, 696 (1959).

69. Dauer, C. C., and Davids, D. J., "1958 Summary of Disease Outbreaks." *Pub. Health Rept.*, **74**, 8, 715 (1959).

70. Davison, R. C., Breese, W. P., Warren, C. E., and Doudoroff, P., "Experiments on the Dissolved Oxygen Requirements of Cold-Water Fishes." *Sewage and Industrial Wastes*, **31**, 8, 950 (Aug. 1959).

71. DeLaney, J. E., "Evaluation of a Hyla Water Purification Unit." *Sanitalk*, **7**, 14 (1958).

72. Dickie, L. M., "Water Temperature and Survival of Giant Scallop." *Trans. Amer. Fish. Soc.*, **88**, 1, 73 (1959).

73. Doret, A. M., "Measures Taken Up to the Present to Maintain the Salubrity of Lake Constance." European Problems in the Protection of Waters. European Federation for the Protection of Waters, 158 pp. (1957); *Water Poll. Abs.* (Brit.), **32**, 3, 545 (1959).

74. Edwards, R. W., "The Effect of Larvae of *Chironomus riparius* Meigen on the Redox Potentials of Settled Activated Sludge." *Ann. Appl. Biol.* (Brit.), **46**, 457 (1958); *Water Poll. Abs.* (Brit.), **32**, 71 (1959).

75. Edwards, R. W., "The Relation of Oxygen Consumption to Body Size and to Temperature in the Larvae of *Chironomus riparius* Meigen." *Jour. Exptl. Biol.* (Brit.), **35**, 383 (1958); *Water Poll. Abs.* (Brit.), **31**, 406 (1958).

76. Eipper, A. W., "Effects of Five Herbicides on Farm Pond Plants and Fish." *N. Y. Fish and Game Jour.*, **6**, 1, 46 (1959).

77. Elipiner, L. I., "Disinfection of Drinking Water by the Combined Action of Ultrasonic Waves and Small Doses of Disinfectants." *Hyg. and San.* (U.S.S.R.), **23**, 7, 26 (1958); *Water Poll. Abs.* (Brit.), **31**, 402 (1958); *Pub. Health Eng. Abs.*, **39**, 7, W31 (1959).

78. Engelbrecht, R. S., and Morgan, J. J., "Studies on the Occurrence and Degradation of Condensed Phosphate in Surface Waters." *Sewage and Industrial Wastes*, **31**, 4, 458 (Apr. 1959).

79. Etinger-Tulczynska, R., "The Effect of Various Water Bacteria on the Growth of *Escherichia coli* I in MacConkey's Broth at 37° and 42°." *Jour. Appl. Bacteriol.* (Brit.), **21**, 2, 174 (1958).

80. Ferguson, R. G., "The Preferred Temperature of Fish and Their Midsummer Distribution in Temperate Lakes and Streams." *Jour. Fish. Res. Bd. Canada*, **15**, 4, 607 (1958); *Sport Fish. Abs.*, **4**, 1, 31 (1959).

81. Filice, F. P., "The Effects of Wastes on the Distribution of Bottom Invertebrates in the San Francisco Bay Estuary." *Wasmann Jour. of Biol.*, **17**, 1, 1 (1959).

82. Floquet, E., "Battling Water Pollution in the Longwy Basin." *Eau* (France), **45**, 304 (1958).

83. Fridlyand, S. A., and Rubleva, M. N., "Determination of the Maximum Permissible Concentrations in the Case of Simultaneous Pollution of Surface Water with Several Substances." *Gigiena i San.* (U.S.S.R.), **23**, 11, 12 (1958); *Chem. Abs.*, **53**, 11, 10607 (1959).

84. Gameson, A. L. H., and Griffith, S. D., "Six Months' Oxygen Records for a Polluted Stream." *Water and Waste Treat. Jour.* (Brit.), **7**, 198 (1959).

85. Gameson, A. L. H., and Truesdale, G. A., "Some Oxygen Studies in Streams." *Jour. Inst. Water Engrs.* (Brit.), **13**, 175 (1959).

86. Gameson, A. L. H., Gibbs, J. W., and Barrett, M. J., "A Preliminary Temperature Survey of a Heated River." *Water and Water Eng.*, **63**, 13 (1959); *Water Poll. Abs.* (Brit.), **32**, 7, 1241 (1959).

87. Garside, E. T., and Tait, J. S., "Preferred Temperature of Rainbow Trout (*Salmo gairdneri* Richardson) and its Unusual Relationship to Acclimation Temperature." *Can. Jour. Zool.*, **36**, 563 (1958).

88. Glenn, T. R., and Cowherd, G. T., Jr., "Sinusoidal Variations in Dissolved Oxygen." *Wastes Eng.*, **30**, 6, 450 (1959).

89. Graham, R. J., and Scott, D. O., "Effects of Forest Insect Spraying on Trout and Aquatic Insects in Some Montana Streams." Mont. Fish and Game Dept., Final Report PR Proj. F-21-R., **3**, 32, 18 (Apr. 1958); *Wildlife Rev.*, **94**, 12 (Feb. 1959).

90. Gray, R. D., "Formate Lactose Glutomate: A Chemically Defined Medium as a Possible Substitute for MacConkey Broth in the Presumptive Coliform Examination of Water." *Jour. Hyg.* (Brit.), **57**, 3, 249 (1959).

91. Graziadei-Celoria, M., "The Search for Enterococci in Drinking Water During 1954–1957." *Riv. Ital. Igiene* (Italy), **18**, 40 (1958); *Excerpta Med.*, Pub. Health, Soc. Med. and Hyg., **5**, 244 (1959); *Pub. Health Eng. Abs.*, **39**, 11, 27 (1959).

92. Guthof, O., and Dammann, G., "The Value of the Enterococcus Test in the Examination of Drinking and Surface Waters." *Arch. Hyg. u. Bakteriol.* (Germany), **142**, 7, 559 (1958); *Bull. Hyg.*, **34**, 359 (1959); *Pub. Health Eng. Abs.*, **39**, 11, 32 (1959).

93. Habs, H., and Langeloh, H., "The Significance of the So-Called Atypical Coliform Bacteria in the Examination of Water." *Arch. Hyg. u. Bakteriol.* (Germany), **142**, 6, 401 (1958); *Bull. Hyg.*, **34**, 359 (1959); *Pub. Health Eng. Abs.*, **39**, 11, 32 (1959).

94. Harkness, N., and Jenkins, S. H., "Chemical and Biological Oxidation of Styrene and Isoprene." *Jour. and Proc., Inst. Sew. Purif.*, Part 2, 216 (1958); *Water Poll. Abs.* (Brit.), **32**, 5, 175 (1959).

95. Harrison, A. D., "The Effects of Organic Pollution on the Fauna of Parts of the Great Berg River System and of the Krom Stream, Stellenbosch." Hydrobiological Studies in the Great Berg River, Western Cape Province. *Trans. Roy. Soc. S. Africa*, **35**, 299 (1958).

96. Harrison, A. D., "Quantitative Studies on Sandy Bottoms, Notes on Tributaries and Further Information on the Fauna, Arranged Systematically." Hydrobiological Studies on the Great Berg River, Western Cape Province. *Trans. Roy. Soc. S. Africa*, **35**, 277 (1958).

97. Harrison, A. D., and Elsworth, J. F., "General Description, Chemical Studies and Main Features of the Flora and Fauna." Hydrobiological Studies on the Great Berg River, Western Cape

Province. *Trans. Roy. Soc. S. Africa*, **35**, 125 (1958).

98. Harrison, A. D., "The Effects of Sulphuric Acid Pollution on the Biology of Streams in the Transvaal, South Africa." *Verh. Int. Ver. Limnol.* (Germany), **13**, 603 (1958); *Water Poll. Abs.* (Brit.), **32**, 3, 548 (1959).
99. Heide, F., and Thiele, A., "The Boron Content of Saale Water." *Naturwissenschaften* (Germany), **45**, 363 (1958); *Water Poll. Abs.* (Brit.), **32**, 16 (1959).
100. Henderson, C., Pickering, Q. H., and Cohen, J. M., "The Toxicity of Synthetic Detergents and Soaps to Fish." *Sewage and Industrial Wastes*, **31**, 3, 295 (Mar. 1959).
101. Henderson, C., Pickering, Q. H., and Tarzwell, C. M., "Relative Toxicity of Ten Chlorinated Hydrocarbon Insecticides to Four Species of Fish." *Trans. Amer. Fish. Soc.*, **88**, 1, 23 (1959).
102. Henderson, W. L., "Studies on the Use of Membrane Filters for the Estimation of Coliform Densities in Sea Water." *Sewage and Industrial Wastes*, **31**, 1, 78 (Jan. 1959).
103. Herbert, D. W. M., and Mann, H. T., "The Tolerance of Some Fresh-Water Fish for Sea Water." *Salm. Trout Mag.* (Brit.), **153**, 99 (1958); *Water Poll. Abs.* (Brit.), **31**, 395 (1958).
104. Hirsch, A., "Biological Evaluation of Organic Pollution of New Zealand Streams." *New Zealand Jour. Sci.*, **1**, 4, 500 (1958).
105. Hoffman, R. A., "Toxicity of Three Phosphorus Insecticides to Cold Water Game Fish." *Mosquito News*, **17**, 213 (1957); *Water Poll. Abs.* (Brit.), **31**, 395 (1958).
106. Hollis, M. D., and McCallum, G. E., "Dilution is no Longer the Solution for Pollution." *Wastes Eng.*, **30**, 10, 578 (1959).
107. Horwitz, E., and Barnett, G. R., "Pollution Control on the Illinois Waterway." *Jour. Amer. Water Works Assn.*, **51**, 8 (1959).
108. Hourston, A. S., and Herlinveaux, R. H., "A 'Mass Mortality' of Fish in Alberni Harbour, B. C." Progr. Rep. Biol. Stas. Nanaimo and Vancouver, **109**, 3, (1957); *Water Poll. Abs.* (Brit.), **31**, 395 (1958).
109. Houston, A. H., "Responses of Juvenile Chum, Pink, and Coho Salmon to Sharp Sea-Water Gradients." *Can. Jour. Zool.*, **35**, 371 (1957); *Sport Fish. Abs.*, **3**, 80 (1958).
110. Hutner, S. H., and McLaughlin, J. J. A., "Poisonous Tides." *Scientific Amer.*, **199**, 92 (1958); *Pub. Health Eng. Abs.*, **39**, 3, 15 (1959).
111. Itazawa, Y., "Gas Content of the Blood in Response to that of Medium Water in Fish." *Bull. Japan Soc. Sci. Fisheries*, **23**, 71 (1957); *Water Poll. Abs.*, **32**, 3, 556 (1959).
112. Jaag, O., "The Protection of the Rhine Against Pollution Based on European Collaboration." European Problems in the Protection of Waters. European Federation for the Protection of Waters, 57 (1957); *Water Poll. Abs.* (Brit.), **32**, 3 (1959).
113. Jaag, O., "Problems and Examples of Stream Protection in the Watershed of the Reuss River." *Wasser- und Energiewirtschaft* (Switzerland) (1958); *Pub. Health Eng. Abs.*, **39**, 11, 23 (1959).
114. Job, S. V., "The Routine-Active Oxygen Consumption of the Milk Fish." *Proc. Indian Acad. Sci.*, Sect. B, **45**, 302 (1957); *Sport Fish. Abs.*, **3**, 200 (1958).
115. Johannesson, J. K., "A Reconnaissance Survey of Pollution in the Manawatu River." *New Zealand Jour. Sci.*, **1**, 554 (1958); *Water Poll. Abs.* (Brit.), **32**, 5, 945 (1959).
116. Katz, M., Pritchard, A., and Warren, C. E., "Ability of Some Salmonids and a Centrarchid to Swim in Water of Reduced Oxygen Content." *Trans. Amer. Fish. Soc.*, **88**, 2, 88 (1959).
117. Keenleyside, M. H. A., "Comparative Effects of the Insecticides DDT and Malathion on Young Atlantic Salmon." Progr. Repts. of the Atlantic Coast Stations, Fish. Res. Bd. of Canada, 69, 3 (1958).
118. Keenleyside, M. H. A., "Effects of Spruce Budworm Control on Salmon and Other Fishes in New Brunswick." *Canadian Fish Culturist*, **24**, 17 (1959).
119. Kerswill, C. J., "Effects of DDT Spraying in New Brunswick on Future Runs of Adult Salmon." *Fish. Res. Bd. of Canada*, 525 (1958); *Water Poll. Abs.* (Brit.), **32**, 4, 744 (1959).
120. Khachidze, S. G., "Accidental Poisoning of Fish in the River Kura." *Gigiena i San.* (U.S.S.R.), **11**, 69 (1956); *Pub. Health Eng. Abs.*, **39**, 4, 27 (1959).
121. King, G. T., "Chemical Manufacturers and Standards for Trade Effluents." Control of River Pollution. *Jour. and Proc., Inst. Sew. Purif.*, Part 4, 490 (1958); *Water Poll. Abs.* (Brit.), **32**, 7 (1959).
122. Kirdorf, W., "Water Protection Areas. Legal Problems and Their Solution in

the Rhineland-Palatinate." *Wasser u. Boden* (Germany), **9**, 9, 345 (1957); *Water Poll. Abs.* (Brit.), **32**, 3, 546 (1959).

123. Kittrell, F. W., "Effects of Impoundments on Dissolved Oxygen Resources." *Sewage and Industrial Wastes*, **31**, 9, 1065 (Sept. 1959).

124. Klimkina, N. V., "Hygienic Norms for the Amounts of the Poisonous Products (Isoprene and Dimethyldioxane) of Synthetic Isoprene-Rubber Production in the Water of Reservoirs." *Gigiena i San.* (U.S.S.R.), **24**, 6, 8 (1959); *Chem. Abs.*, **53**, 20, 19238 (1959).

125. Klinger, K., "Sodium Nitrite, a Slow-Acting Fish Poison." *Schweiz. Z. Hydrol.* (Switzerland), **19**, 2, 565 (1957); *Biol. Abs.*, **32**, 8, 27214 (1958).

126. Knorr, M., "Petroleum Products in Soil and Underground Water." *Water* (Netherlands), **41**, 247 (1957); *Chem. Abs.*, **53**, 11, 10607 (1959).

127. Krombach, H., "Considerations on the Chemical Composition of Waters of the Moselle Along the Luxembourg Frontier." European Problems in the Protection of Waters. European Federation for the Protection of Waters, 97 (1957); *Water Poll. Abs.* (Brit.), **32**, 3, 545 (1959).

128. Kubelka, V., "The Pollution Problem from Industrial Waste Water, with Particular Reference to Tannery Wastes." Bratislava, Superior Tech. School (Czech.), *Rev. Tech. Ind. Cuir*, **50**, 147 (1958); *Chem. Abs.*, **53**, 8, 7473 (1959).

129. Kühl, H., and Mann, H., "The Behavior of Inorganic Nitrogen Compounds in the Estuary of a River." *Arch. Fischwiss.* (Germany), **9**, 9 (1958); *Water Poll. Abs.* (Brit.), **32**, 7, 250 (1959).

130. Kuhnemann, O., "Modification of the Plankton of the Water of the Rio de la Plata During Storage in an Artificial Lake." Actas de Tercer Congreso Ingenieria Sanitaria Interamericano (Argentina), 689 (1952); *Pub. Health Eng. Abs.*, **39**, 11, 23 (1959).

131. Kuper, A. I., "The Sanitary Characteristics of the Kama River in the Region of the Release of Sewage from an Aniline Dyeworks." *Gigiena i San.* (U.S.S.R.), **2**, 61 (1957); Abs. *Soviet Med.*, **2**, 3, 981 (1958); *Pub. Health Eng. Abs.*, **39**, 3, 35 (1959).

132. La Berge, R. H., "Thermal Discharges." *Water and Sewage Works*, **106**, 536 (1959).

133. Lackey, J. B., "Turbidity Effects in Natural Waters in Relation to Organisms and the Uptake of Radioisotopes." Sixth Ontario Ind. Waste Conf., 37 (1959).

134. Laubusch, E. J., "How Safe is Your Chlorine Residual?" *Pub. Works*, **90**, 102 (1959).

135. Lawrence, J. M., "Recent Investigations on the Use of Sodium Arsenite as an Algicide and Its Effects on Fish Production in Ponds." Proc. 11th Ann. Conf., Southeastern Assn. Game and Fish Comm., 281 (1958).

136. Lebedeva, G. D., "Plankton as Indicator of Radioactive Contamination of Fresh Water Reservoirs." *Med. Radiol.*, **2**, 6, 65 (1957); *Pub. Health Eng. Abs.*, **39**, 9, 31 (1959).

137. Leclerc, H., "Presence of Vi-Phages in Waters in the Hanoi (N. Vietnam) Region." *Ann. Inst. Pasteur* (France), **92**, 369 (1957); *Jour. Amer. Water Works Assn.*, **51**, 5, P&R 68 (1959).

138. LeClerc, E., "The Significance and the Possibilities of Purification of Non-organic Industrial Effluents." *Schweiz. Z. Hydrol.* (Switzerland), **19**, 1, 515 (1957); *Pub. Health Eng. Abs.*, **39**, 27 (1959).

139. Levin, G. V., Harrison, V. R., Hess, W. C., Heim, A. H., and Strauss, V. L., "Rapid, Radioactive Test for Coliform Organisms." *Jour. Amer. Water Works Assn.*, **51**, 1, 101 (1959).

140. Liebmann, H., "Means of Purifying the Danube." European Problems in the Protection of Waters. European Federation for the Protection of Waters, 37 (1957); *Water Poll. Abs.* (Brit.), **32**, 3 (1959).

141. Lindahl, P., and Marcstrom, A., "On the Preference of Roaches (*Leuciscus rutilus*) for Trinitrophenol, Studied with the Fluviarium Technique." *Jour. Fish. Res. Bd. Canada*, **15**, 4, 685 (1958); *Biol. Abs.*, **33**, 4, 12659 (1959).

142. Lisovskaya, E. V., "Experimental Data for the Basing of the Maximum Permissible Concentration of Metaphos in Surface Waters." *Hyg. and San.* (U.S.S.R.), **23**, 12, 19 (1958); *Water Poll. Abs.* (Brit.), **32**, 7, 1346 (1959).

143. Lohr, "Authorities and Sewage Disposal in Bavaria." *Ber. Abwassertechn. Verein.* (Germany), **6**, 149 (1955); *Water Poll. Abs.* (Brit.), **32**, 4, 728 (1959).

144. Lovett, M., "Standards: Some Pros and Cons." Control of River Pollution. *Jour. Inst. Sewage Purif.* (Brit.), **4**, 409 (1958); *Water Poll. Abs.* (Brit.), **32**, 7 (1959).

145. Lozinov, A. B., "The Oxygen Optimum of Sturgeon Young." *Doklady Akad. Nauk* (U.S.S.R.), **107**, 337 (1956); *Sport Fish. Abs.*, **3**, 211 (1958).

146. Lumbye, J., "The Oxygen Consumption of *Theodoxus fluviatilis* (L.) and *Potamopyrgus jenkinsi* (Smith) in Brackish and Fresh Water." *Hydrobiologia* (Denmark), **10**, 245 (1958); *Water Poll. Abs.* (Brit.), **31**, 373 (1958).

147. MacLeod, J. C., "The Effects of Industrial Pollution on Fresh Water Fisheries in British Columbia." *Canadian Fish Culturist*, **25**, 49 (1959).

148. MacPherson, L. B., Sinclair, N. R., and Hayes, F. R., "Lake Water and Sediment. III. The Effect of pH on the Partition of Inorganic Phosphate Between Water and Oxidized Mud or its Ash." *Jour. Limn. and Ocean.*, **3**, 318 (1958).

149. Mann, K. H., "Seasonal Variation in the Respiratory Acclimatization of the Leech *Erpobdella testacea* (Sav.)." *Jour. Exptl. Biol.* (Brit.), **35**, 314 (1958); *Water Poll. Abs.* (Brit.), **31**, 406 (1958).

150. Marei, A. N., Saurov, M. M., and Lebedeva, G. D., "On Transmission of Radio-Strontium by Nutritional Chain from Open Water Reservoirs into the Human Organism." *Nuclear Sci. Abs.*, **12**, 1122 (1958); *Water Poll. Abs.* (Brit.), **32**, 141 (1959).

151. McCallum, G. E., "Jurisdiction Over Pollution—The Federal View on Water Pollution." *Chem. Processing*, **21**, 32 (1958); *Pub. Health Eng. Abs.*, **39**, 25 (1959).

152. Mekhanik, F. Y., "Growth and Metabolism in the Young of the Ladogian Salmon and Rainbow Trout at Various Temperatures." *Zool. Zhur.* (U.S.S.R.), **35**, 290 (1955); *Sport Fish. Abs.*, **3**, 200 (1958).

153. Mercier, P., "Natural and Artificial Aeration of Lakes. Fulfillment at Lake Bret and Possibility of Application at Lake Morat." *Schweiz. Z. Hydrol.* (Switzerland), **19**, 613 (1957).

154. Metzler, D. F., "The Re-Use of Treated Waste Water for Domestic Purposes." *Pub. Works*, **90**, 117 (1959).

155. Mikhalyuk, I. A., "Varying Results of the Bacteriological Examination of Water Depending on Time of Collection and Conditions of Transport of Samples." *Vrachebnoe Delo* (U.S.S.R.), **3**, 287 (1957); *Excerpta Med.*, Pub. Health, Soc. Med. & Hyg., **4**, 604 (1958); *Pub. Health Eng. Abs.*, **39**, 1/2, 14 (1959).

156. Milbauer, R., and Grossowicz, N., "Effect of Growth Conditions on Chlorine Sensitivity of *Escherichia coli*." *Appl. Microbiol.*, **7**, 2, 71 (1959).

157. Milbauer, R., and Grossowicz, N., "Reactivation of Chlorine—Inactivated *Escherichia coli*." *Appl. Microbiol.*, **7**, 2, 67 (1959).

158. Mori, T., and Saiki, M., "Radioactivity of Fishes Contaminated by Nuclear-Bomb Test Explosions with Special Reference to the Nuclides." Nippon *Nogei-kagaku Kaishi* (Japan), **31**, A79 (1957); *Pub. Health Eng. Abs.*, **39**, 3, 23 (1959).

159. Moyle, J. B., and Clothier, W. D., "Effects of Management and Winter Oxygen Levels on the Fish Population of a Prairie Lake." *Trans. Amer. Fish. Soc.*, **88**, 178 (1959).

160. Nasarenko, I. W., "Methanol and Acetone as Factors in the Industrial Pollution of Surface Waters." *Hyg. and San.* (U.S.S.R.), **20**, 12, 42 (1955); *Chem. Zbl.*, **128**, 5676 (1957); *Water Poll. Abs.* (Brit.), **32**, 7, 250 (1959).

161. Neale, A. T., "Pulp and Paper Mill Wastes in Washington." *Ind. Wastes*, **3**, 29 (1958).

162. Neil, J. H., "Some Effects of Potassium Cyanide on Eastern Brook Trout (*Salvelinus fontinalis*)." 4th Ontario Ind. Waste Conf., 74 (1957); *Chem. Abs.*, **53**, 12500 (1959).

163. Newell, G. E., "Pollution and the Abundance of Animals in Estuaries." Symp. Effects of Poll. on Living Materials. Inst. Biol. (1958); *Water Poll. Abs.* (Brit.), **32**, 2, 373 (1959).

164. Nicholson, H. P., "Insecticide Pollution of Water Resources." *Jour. Amer. Water Works Assn.*, **51**, 8, 981 (1959).

165. Noble, R. E., and Reitman, M., "Influence of Basic Fuchsin and Sodium Sulfite on EHC Endo Membrane Filter Medium." *Jour. Amer. Water Works Assn.*, **51**, 5, 614 (1959).

166. Numann, W., "Natural and Artificial 'Red Water' with Consequent Death of Fish in the Sea." *Arch. Fischwiss.* (Germany), **8**, 204 (1957); *Water Poll. Abs.* (Brit.), **31**, 406 (1958).

167. Ogden, C. G., Gibbs, J. W., and Gameson, A. L. H., "Some Factors Affecting the Aeration of Flowing Saline Water." *Water and Waste Treat. Jour.* (Brit.), **7**, 9, 392 (1959).

168. Okada, S., and Uesugi, K., "Quality of the River Water and its Pollution." *Himeji Kogyo Daigaku Kenkyu Hokoku* (Japan), **8**, 78 (1958);

Chem. Abs., **52**, 14909 (1958); *Water Poll. Abs.* (Brit.), **32**, 4, 739 (1959).

169. Okubo, K., "Study on the Bio-Assay Method for the Evaluation of Water Pollution—I. An Attempt to Use Brine Shrimp as a Test Animal." Bull. Tokai Reg. Fish. Res. Lab. (Japan), **18**, 31 (1957); *Biol. Abs.*, **33**, 8, 28640 (1959).

170. Oldham, L. W., "Investigations into the Effects of a Non-Ionic Synthetic Detergent on Biological Percolating Filters." *Jour. Inst. Sewage Purif.* (Brit.), **2**, 136 (1958); *Water Poll. Abs.* (Brit.), **32**, 5, 164 (1959).

171. Olsen, S., "Phosphate Adsorption and Isotopic Exchange in Lake Muds. Experiments with Phosphorus-32. Preliminary Report." *Verh. Int. Ver. Limnol.* (Germany), **13**, 915 (1956); *Water Poll. Abs.*, **32**, 7 (1959).

172. Paffenbarger, R. S., Jr., *et al.*, "Viruses and Illnesses in a Boys' Summer Camp." *Amer. Jour. Hyg.*, **70**, 254 (1959).

173. Palange, R. C., Henderson, C., Cohen, J. M., and McDermott, G. N., "Wastes from the Production of Reactor-Grade Zirconium." *Sewage and Industrial Wastes*, **31**, 5, 565 (May 1959).

174. Pandelescu, M. R., and Rosu, I., "Observations on the Isolation of *Salmonella typhi* from Water by the Precipitation Method." *Igiena* (Hungary), **6**, 357 (1957); *Bull. Hyg.*, **33**, 773 (1958); *Pub. Health Abs.* (Brit.), **39**, 14 (1959).

175. Poehlmann, H., "How Stands the Rhine?" Mitt. Ver. Deutsche Gewässerschutz (Germany), 7 (1957); *Water Poll. Abs.* (Brit.), **31**, 323 (1958); *Pub. Health Eng. Abs.*, **39**, 4, 27 (1959).

176. Price, S. A., and Gare, L., "A Source of Error in Microbiological Assays Attributable to a Bacterial Inhibitor in Distilled Water." *Nature* (Brit.), **183**, 838 (1959); *Pub. Health Eng. Abs.*, **39**, 10, 88 (1959).

177. Privol'nev, T. I., "The Reaction of Fish to Light." *Voprosy Ikhtiologii* (U.S.S.R.), **6**, 3 (1956); *Sport Fish. Abs.*, **3**, 209 (1958).

178. Rand, M. C., "Laboratory Studies of Sewage Effects on Atmospheric Reaeration." *Sewage and Industrial Wastes*, **31**, 10, 1197 (Oct. 1959).

179. Rao, K. P., "Oxygen Consumption as a Function of Size and Salinity in *Metapenaeus monoceros* Fab. from Marine and Brackish-Water Environments." *Jour. Exptl. Biol.* (Brit.), **35**, 307 (1958); *Water Poll. Abs.* (Brit.), **31**, 406 (1958).

180. Rawn, A M, "Bacterial Monitoring Guards Coastal Recreation Waters." *Wastes Eng.*, **30**, 4, 188 (1959).

181. Ray, S. M., and Wilson, W. B., "Effects of Uni-Algal and Bacteria-Free Cultures of *Gymnodinium brevis* on Fish." *Fish Bull.*, U. S. Fish and Wildlife Serv., **57**, 469 (1957); *Water Poll. Abs.* (Brit.), **32**, 7, 1344 (1959).

182. Reich, K., and Rotberg, M., "Some Factors Influencing the Formation of Toxin Poisonous to Fish in Bacteria-Free Cultures of Prymnesium." *Bull. Res. Coun. Israel*, **7B**, 199 (1958); *Water Poll. Abs.* (Brit.), **32**, 4, 749 (1959).

183. Renn, C. E., and Barada, M. F., "Adsorption of ABS on Particulate Materials in Water." *Sewage and Industrial Wastes*, **31**, 7, 850 (July 1959).

184. Rice, T. R., and Willis, V. M., "Uptake, Accumulation and Loss of Radioactive Cerium-144 by Marine Planktonic Algae." *Jour. Limn. and Ocean.*, **4**, 277 (1959).

185. Rosenthal, H. L., "The Metabolism of Strontium-90 and Calcium-45 by *Lebistes*." *Biol. Bull., Wood's Hole*, **113**, 442 (1957); *Water Poll. Abs.* (Brit.), **31**, 431 (1958).

186. Ruffel, M. A., "Determination of the Dilution Rate of Sewage for the Sanitary Control of Water Reservoirs." *Gigiena i San.* (U.S.S.R.), **3**, 19 (1958); *Pub. Health Eng. Abs.*, **39**, 9, 25 (1959).

187. Saha, K. A., Sen, D. P., and Mazumdar, P., "Studies on the Mortality of Spawn and Fry of Indian Major Carps During Transport. III. Effect of Inimical Substances from Decomposition of Metabolic Products in the Medium of Spawn Life and Their Control." *Indian Jour. Fish.*, **3**, 135 (1956); *Sport. Fish. Abs.*, **3**, 143 (1958).

188. Saurov, M. M., "Radioactive Contamination of Fish in Waters Containing Strontium." Trud. Vses. Konf. Med. Radiol., Vopr. Gig. Dozimetr. (U.S.S.R.), 66 (1957); *Water Poll. Abs.* (Brit.), **32**, 107 (1959).

189. Schiavone, E. L., and Passerini, L. M. D., "The Genus *Pseudomonas aeruginosa* in the Judgment of the Potability of Drinking Water." *Sem. Med.* (Argentina), **111**, 23, 1151 (1957); *Excerpta Med.*, Pub. Health, Soc. Med. and Hyg., **4**, 684 (1958);

Pub. Health Eng. Abs., **39**, 4, 35 (1959).

190. Schiffman, R. H., and Fromm, P. O., "Chromium-Induced Changes in the Blood of Rainbow Trout (*Salmo gairdnerii*)." *Sewage and Industrial Wastes*, **31**, 2, 205 (Feb. 1959).
191. Schinzel, A., Augste, G., and Locker, F., "Importance of Limnological (Hydrobiological) Investigations in the Study of Waters from Limestone Formations." *Arch. Hyg. u. Bakteriol.* (Germany), **142**, 540 (1958); *Pub. Health Eng. Abs.*, **39**, 11, 22 (1959).
192. Schmassmann, H., "Some Observations on the Results of the Investigation of the Rhine on 13th and 14th March 1956." Wasser u. Energiew. (Switzerland), 11 (1957); *Water Poll. Abs.* (Brit.), **32**, 5, 943 (1959).
193. Schuh, R., "Measuring Apparatus for the Investigation and Supervision of Rivers and Waste Waters." *Wasserwirtsch.*, Stuttgart (Germany), **48**, 315 (1958); *Water Poll. Abs.* (Brit.), **32**, 6, 1019 (1959).
194. Scott, D. C., "Biological Balance in Streams." *Sewage and Industrial Wastes*, **30**, 9, 1169 (Sept. 1958).
195. Scott, K. H. F., "The Chironomidae." Hydrobiological Studies on the Great Berg River, Western Cape Province. *Trans. Roy. Soc. S. Africa*, **35**, 277 (8195).
196. Seabloom, R. W., "Water Quality Studies in the Wenatchee River Basin." U. S. Fish and Wildlife Service Sp. Scien. Rept., Fish. No. 268 (1958).
197. Seymour, A., "Effects of Temperature Upon the Formation of Vertebrae and Fin Rays in Young Chinook Salmon." *Trans. Amer. Fish. Soc.*, **88**, 1, 58 (1959).
198. Shamardina, I. P., "Changes in the Intensity of Respiration of Fish in the Course of Their Development." *Loklady Akad. Nauk* (U.S.S.R.), **98**, 689 (1954); *Sport Fish. Abs.*, **3**, 144 (1958).
199. Shekhanova, I. A., "The Possibility of Assimilation of Inorganic Phosphorus from the Water by Fish." *Doklady Akad. Nauk* (U.S.S.R.), **106**, 161 (1956); *Sport. Fish. Abs.*, **3**, 146 (1958).
200. Shiyazuki, K., and Hayama, K., "Polluted Water Drainage from Factories. VII. Influence of the Waste Liquor on Kasado Bay. VIII. Treatment of the Waste Liquor from Coal-Gas Plants." *Norinsho Suisan Koshusho Kenkyuhokoku* (Japan), **6**, 249 (1957); and **7**, 101 (1958); *Water Poll. Abs.* (Brit.), **32**, 4, 738 (1959).
201. Stammer, H. A., "Toxicity Towards Fish Shown by Various Slime-Controlling Agents Used in the Paper and Pulp Industry." *Papier*, Darmstadt (Germany), **12**, 41 (1958); *Water Poll. Abs.* (Brit.), **31**, 395 (1958).
202. Steen, H., "Determinations of the Solubility of Oxygen in Pure Water." *Jour. Limn. and Ocean.*, **3**, 423 (1958); *Water Poll. Abs.* (Brit.), **32**, 6, 196 (1959).
203. Straub, L. G., and Anderson, A. G., "Experiments on Self-Aerated Flow in Open Channels." *Proc. Amer. Soc. Civil Engrs.*, **84**, HY7, 1890, 35 (1958).
204. Strickland, J. D. H., "Solar Radiation Penetrating the Ocean. A Review of Requirements, Data and Methods of Measurement, with Particular Reference to Photosynthetic Productivity." *Jour. Fish. Res. Bd. Canada*, **15**, 453 (1958); *Water Poll. Abs.* (Brit.), **32**, 4, 648 (1959).
205. Stringer, G. E., and McMynn, R. G., "Experiments with Toxaphene as Fish Poison." *Canadian Fish Culturist*, **23**, 39 (1958); *Sport Fish. Abs.*, **4**, 1, 15 (1959).
206. Sturdza, S. A., and Pandelescu, M. R., "The Importance of Detection of Bacteriophage in Stream Investigations." *Städtchygiene* (Germany), **9**, 81 (1958); *Water Poll. Abs.* (Brit.), **32**, 616 (1959); *Pub. Health Eng. Abs.*, **39**, 11, 29 (1959).
207. Surber, E. W., "*Cricotopus bicinctus*, a Midgefly Resistant to Electroplating Wastes." *Trans. Amer. Fish. Soc.*, **88**, 2, 111 (1959).
208. Tarpley, W. A., "Studies on the Use of the Brine Shrimp *Artemia salina* (Leach) as a Test Organism for Bioassay." *Jour. Econ. Entomology*, **51**, 6, 780 (1958).
209. Tarzwell, C. M., "Disposal of Toxic Wastes." *Ind. Wastes*, **4**, 5, 136 (1959).
210. Tarzwell, C. M., "Some Pollutional Effects of Organic Insecticides." Trans. 24th North Amer. Wildlife Conf., 132 (1959).
211. Tarzwell, C. M., "The Toxicity of Some Organic Insecticides to Fishes. The Fire Ant Eradication Program and How it Affects Wildlife." Proc. 12th Ann. Conf. Southeast Assn. Game Fish Comm., 233 (1958).
212. Thomas, S. B., Hobson, P. M., and Druce, R. G., "Coli-Aerogenes Bacteria in Farm Water Supplies." *Jour. Appl. Bacteriol.*, **22**, 1, 32 (1959).

213. Truesdale, G. A., "Foaming of Liquids Containing Synthetic Detergents." *Water and Waste Treat. Jour.* (Brit.), **7**, 108 (1958); *Water Poll. Abs.* (Brit.), **32**, 5, 165 (1959).

214. Tucker, D. S., "The Distribution of Some Freshwater Invertebrates in Ponds in Relation to Annual Fluctuations in the Chemical Composition of the Water." *Jour. Animal Ecol.*, **27**, 105 (1958).

215. Turnbull-Kemp, P. St. J., "Trout in Southern Rhodesia. V. Toxicity of Copper Sulfate to Trout." *Rhodesia Agr. Jour.*, **55**, 637 (1958); *Chem. Abs.*, **53**, 15384 (1959).

216. Vinberg, G. G., and Sivko, T. N., "Phytoplankton as an Agent in Self-Purification of Polluted Water." *Trudy Vsesoyuz. Gidrobiol. Obshchestva* (U.S.S.R.), **7**, 3 (1956); *Pub. Health Eng. Abs.*, **39**, 4, 34 (1959).

217. Vivier, P., "Action of Waste Waters on Some Lakes and Rivers in France." *Bull. Centre Belge Etude et Document. Eaux* (Belgium), **43**, 32 (1959); *Pub. Health Eng. Abs.*, **39**, 11, 24 (1959).

218. Vliet, R. V., "Effect of Heated Condenser Discharge Water Upon Aquatic Life." Amer. Soc. Mech. Engrs., 57-PWR-4 (1957).

219. Vollenweider, R. A., and Ravera, O., "Preliminary Observations on the Oxygen Uptake by Some Freshwater Zooplankters." *Verh. Int. Ver. Limnol.* (Germany), **13**, 369 (1958); *Water Poll. Abs.* (Brit.), **32**, 6, 1008 (1959).

220. Waldichuk, M., "Shellfish Toxicity and the Weather in the Strait of Georgia During 1957." *Fish, Res. Bd. Canada*, Progr. Rept. Pacific Coast Stations, **112**, 10 (1958).

221. Webb, W. E., "Toxicity of Eight Different Pesticides to Fish." Idaho Fish and Game Dept., Fish. Div., Progr. Rept. F 34-R-2 (May 1959).

222. Weber, E. W., "Activities of the International Joint Commission, United States and Canada." *Sewage and Industrial Wastes*, **31**, 1, 71 (Jan. 1959).

223. Weber, G., "Chemical and Bacteriological Investigations of Ground Water During an Epidemic of Hepatitis." *Österr. Wasser.* (Austria), **10**, 110 (1958); *Water Poll. Abs.* (Brit.), **32**, 731 (1959); *Pub. Health Eng. Abs.*, **39**, 11, 27 (1959).

224. Weiss, C. M., "The Determination of the Presence of Organic Phosphorus Insecticides in Water by Interaction with Specific Fish Enzymes." Symp. Organic Chemicals in Water. 136th Amer. Chem. Soc. Meeting (Sept. 1959).

225. Weiss, C. M., "Response of Fish to Sublethal Exposures of Organic Phosphorus Insecticides." *Sewage and Industrial Wastes*, **31**, 5, 580 (May 1959).

226. Welsh, H. H., *et al.*, "Q Fever Studies. XXI. The Recovery of *Coxiella burnetii* from the Soil and Surface Water of Premises Harboring Infected Sheep." *Amer. Jour. Hyg.*, **70**, 1, 14 (1959).

227. Whitney, A. N., and Bailey, J. E., "Detrimental Effects of Highway Construction on a Montana Stream." *Trans. Amer. Fish. Soc.*, **88**, 1, 72 (1959).

228. Whitney, A. N., and Spindler, J. C., "Effects of Kraft Paper Wastes on a Montana Stream." *Trans. Amer. Fish. Soc.*, **88**, 2, 153 (1959).

229. Wilhelm, F., "Preliminary Report on Temperature and Oxygen Uptake in the Schliersee in 1956." *Limnol. Schriftenreihe* (Germany), **5**, 19, 40 (1958); *Pub. Health Eng. Abs.*, **39**, 7, 28 (1959).

230. Wilkinson, L., "Sampling Tidal Waters." *New Zealand Jour. Sci. Tech.*, **2**, 196 (1959).

231. Witzel, G., "Compensation from Foreigners for Damage by Pollution of Boundary Waters." *Wasserwirtsch.*, Stuttgart (Germany), **48**, 81 (1958); *Water Poll. Abs.* (Brit.), **31**, 392 (1958).

232. Wood, M. L., "Biological Aspects of Stream Pollution Control in Arkansas." Proc. Ann. Conf. Southeast Assn. Game Fish Comm., 10, 136 (1957).

233. Yakovenko, V. A., "The Sanitary Protection of Sea Waters Near the Seaside Towns." *Sborn. Vopr. Kommun. i Shkoln. Gig.* (Kiev) (U.S.S.R.), 101 (1956); *Pub. Health Eng. Abs.*, **39**, 4, 27 (1959).

234. Yurgenson, L. A., "Sanitary Evaluation of the Sewage Waters of the Bituminous Chemical Plant 'Kiviyli'." *Gigiena i San.* (U.S.S.R.), **2**, 63 (1957); *Pub. Health Eng. Abs.*, **39**, 4, 27 (1959).

235. Zehender, F., "Duties and Activities of the International Commission for the Protection of the Rhine Against Pollution." Plan, Schweizerische Zeitschrift fur Landes-, Regional- und Ortsplanung (Switzerland), 3 (1956); *Pub. Health Eng. Abs.*, **39**, 11 (1959).

236. Zhakov, Y. A., "Maximum Permissible Concentration of Ursol D in Reser-

voirs." (F. F. Erisman Sci.-Res. Inst. of San. and Hyg.). *Gigiena i San.* (U.S.S.R.), **23**, 5, 14 (1958); *Chem. Abs.*, **52**, 16, 14035 (1958).

237. Zhumatov, Kh. Zh., and Dardik, F. G., "An Outbreak of Botkin's Disease of Water Origin." *Vop. Virusol.* (U.S.S.R.), **1**, 39 (1958); *Pub. Health Eng. Abs.*, **39**, 6, 23 (1959).

238. Zieminska, S., "Comparative Studies on the Presence of Bacteria of the *E. coli* Group and Bacteriophages of Some Pathogenic Intestinal Bacteria in River Water." *Roczniki Panstwowego Zakladu Hig.* (Poland), **9**, 3, 225 (1958); *Pub. Health Eng. Abs.*, **39**, 10 (1959).

239. Zyabbarova, S. A., "Determination of the Maximum Permissible Concentration of Pyridine in the Water of a Reservoir." *Hyg. & San.* (U.S.S.R.), **23**, 7, 30 (1958); *Pub. Health Eng. Abs.*, **39**, 7, 36 (1959).

PHILADELPHIA MEETING

- Reserve First Week of October
- For the Federation Meeting
- In Philadelphia
- Social Headquarters at the Sheraton
- Meetings and Exhibits in Convention Hall
- Outstanding Technical Papers
- Industry Day Wednesday
- Special Inspection Trips
- Busy Days for Ladies
- Social Events For All
- Watch Your Mail For Detailed Convention Announcement

Sewage Works

A PAPER CHROMATOGRAPHIC METHOD FOR VOLATILE ACIDS *

By A. M. Buswell, John R. Boring III, and James R. Milam

Research Professor, Research Assistant, and Interim Research Assistant, University of Florida, Gainesville, Fla.

The tentative method for determining volatile acids in digesting sludge as described in "Standard Methods" (1) is a modification of the Duclaux test (2). It is empirical and approximate; laborious and time-consuming; but has served as a means for digestion control for 30 years. Sawyer (3) says, "The value of volatile acid data in the routine control of anaerobic digestion units . . . has been amply demonstrated." The steam distillation method, as given in "Standard Methods," though more accurate, is exacting and laborious. A simpler test and one capable of indicating qualitatively at least whether acetic acid alone is produced or whether propionic and butyric are also produced has long been the hope of workers in this field. For plant operation a test which would detect volatile acids in the range of 500 to 1,000 mg/l would be useful for routine control.

In the early work by Buswell *et al.* (4) on the products of anaerobic decomposition of glucose, the identification of the volatile acids was accomplished by preparing various derivatives, e.g., esters, and obtaining fractional separation of these compounds. This is a very tedious and elaborate process but was the best procedure available 25 years ago. Since that time the need for simpler and more rapid methods in other fields of biochemistry has stimulated a great deal of research.

Of the various advances occurring as a result of this research, methods involving the various techniques of chromatography † (Cg) have shown the most promise. Both column and paper chromatographic methods now make it possible to determine the lower fatty acids, both qualitatively and quantitatively, with a fraction of the labor required by the older methods. The literature in this field is exceedingly voluminous. From the hundreds of available references five selected articles are mentioned briefly in the following paragraphs.

Earlier Work

Mueller *et al.* (5) and Mueller *et al.* (6) use silica gel columns and titration of the eluent fractions. For work in this area it is desirable to determine volatile acids in the range of 1,000 mg/l as acetic without concentration of sample. The methods employed in these papers used 30 ml of sample and did not yield reproducible results in

* Presented at the 32nd Annual Meeting, Federation of Sewage and Industrial Wastes Assns.; Dallas, Tex.; Oct. 12–15, 1959.

† Chromatography: A method of chemical analysis applicable to solutions and gases depending on the fact that different molecules move at different rates which differences are increased by choice of solvents and stationary solid surfaces over or through which the solution (or gas mixture) of the molecules is made to travel. Typically, a two phase setup. Abbreviation, Cg.

the desired range. Concentration of the sample by about 10 to 1 is necessary. This would involve as much work as a Duclaux distillation.

A gas-liquid Cg procedure was suggested by James and Martin (7). These authors used purified diatomaceous earth treated with silicone and stearic acid in a 4-ft glass column (4 mm ID) to determine volatile acids from C_1 to C_{10} (longer columns also were used). The column was heated by vapor (water or methanol) and the carrier gas was nitrogen. Gas and volatile acids vapor were bubbled through an automatic titration cell using methyl red indicator. The minimum amount detectable was 0.02 mg acetic. When the acids are present as their salts they must be converted to the free acids by treating with H_3PO_4 and extracting as described by the authors. This procedure, while accurate, requires expensive apparatus and is slow and laborious.

Duncan and Porteous (8) used *n*-butanol and 1.5 N NH_4OH as moving phase on paper for quantitative separation and estimation of volatile acids from C_2 to C_6, refining the method of Reid and Lederer (9). They claim quantitative results in the range of 16 to 80 μg/5μl for C_2 to C_6.

Hiscox and Berridge (10) describe a simplified method for paper partition Cg separation of volatile acids in which the area of the spot is roughly proportional to the amount of acid present. These authors substitute ethyl amine for the ammonia used by previous workers. "4μl of N/10 acid gave a spot, N/100 better, and N/1,000 just detectable" they say. For acetic (mol wt 60) this corresponds to 24 μg, 2.4 μg, and 0.24 μg, respectively.

Butanol equilibrated with 1.5 N ethylamine is the moving phase, water is the stationary phase, and brom cresol green (2 per cent in ethyl alcohol) the indicator. R_f values with ethylamine were nearly twice as large as with ammonia. The butanol was evaporated off the Cg with cool air. Warm air removed ethylamine acetate. The acid is added to the paper in water solution in a strong atmosphere of amine or by neutralizing the acid with amine to BCG end point before adding to the paper. In the latter case, a blue spot on yellow background develops, and the colors are permanent for 30 min.

Current Tests

The method of Hiscox and Berridge was considered the most suitable and was tested, as described below.

Chemistry of the Test

The volatile acids are present in digester liquor as salts (e.g., NaAc and $CaAc_2$). These salts react with ethylamine according to the following:

$$NaAc + C_2H_5NH_3OH \rightleftarrows NaOH + C_2H_3NH_3Ac \quad (1)$$

next,

$$2NaOH + CO_2 \rightleftarrows Na_2CO_3 + H_2O \quad (2)$$

NaAc is insoluble in butanol hence when the paper is wetted by the eluent, the reaction shown in Equation 1 goes to the right and EtAmAc is drawn up the paper by the butanol. Na_2CO_3 and other mineral salts are relatively insoluble in butanol and remain where the sample is spotted or creep a short distance. When the elution has proceeded far enough to insure the separation of the amine salt from the original spot the strip is removed and exposed in a hood until the butanol and excess amine evaporate. An appreciable amount of water is retained by the paper. Since the amine is a strong base and acetic, a weak acid, alkaline hydrolysis occurs as follows:

$$C_2H_5NH_3Ac + H_2O \rightleftarrows HAc + C_2H_5NH_3^+ + OH^- \quad (3)$$

and on spraying the strip with an acid-base indicator (BCG) two alkaline

spots appear, one at the starting line due to Na_2CO_3 and one higher up due to the hydrolyzed amine. If propionic and butyric acids are also present, their amine salts move faster than the acetate and a third and fourth alkaline spot will appear.

Reagents and Equipment

1. Test solution: 2.73 g sodium acetate/l (2,000 mg/l volatile acids as acetic) (or 4.53 g $NaAc \cdot 3H_2O$).
2. Ethylamine: reagent grade, 72.9-per cent water solution. Dilute to 2.0 N with distilled water for use.
3. *n*-butanol: reagent grade.
4. Butanol-ethylamine eluent: shake vigorously 1 part by volume of 2.0 N ethylamine solution with 4 parts by volume of *n*-butanol, allow to stand until two layers are formed. Decant upper layer for use as the carrier phase.
5. Brom cresol green: indicator grade (0.4 per cent in 95-per cent ethyl alcohol).
6. Whatman No. 1 filter paper: strips, 30 cm × 3 cm with starting line marked 3 cm from bottom.
7. Chromatogram chamber: 500-ml cylinders provided with cork stoppers covered with paper towel for tight fit serve for single strips. Hooks made from paper clips are inserted to suspend the strips. A battery jar covered with plate glass and sealed with vaseline will serve for multiple strips. For descending elution special chambers (available commercially) are desirable.
8. Micropipette: graduate to 0.01 ml.
9. Chromatographic atomizer: available commercially.
10. Air compressor: 2 to 3 psi.

Procedure

Dilute test solution to anticipated concentrations of unknown. Spot paper strips at starting line with test solution in 0.005- to 0.01-ml increments allowing spots to dry between each addition. Place eluent in chamber to 2- to 3-cm depth, suspend paper strips in chamber so as to dip 5 mm into eluent solutions; cover chamber and make air tight.

Allow to stand 4 hr.

Remove paper strips, mark height of carrier liquid with pencil, and dry at room temperature in ventilated hood.

Apply indicator with atomizer sparingly. Hold atomizer 20 cm from strip.

Outline spots with pencil and calculate R_f values. Spot center height/eluent height.

Treat unknown samples in similar manner and compare R_f values and estimate volatile acids content (method should be sensitive to 500 mg/l).

Experimental Results

Exploratory Runs

A large number of exploratory experiments were carried out, including tests with various laboratory cultures showing high volatile acids concentrations; known concentrations of sodium salts of acetic, propionic, and butyric acid in distilled water; and digester liquor of less than 100 mg/l volatile acids content. Variations in reagent concentration and details in technique were investigated.

From these experiments the following general conclusions were reached:

1. The amount of sample added to the paper strip should produce a wet spot of 10- to 15-mm diameter; 0.005 ml and 0.010 ml samples fell within this range.
2. The chamber should be kept saturated with eluent components.
3. After elution the strips must not be dried too long or at too high a temperature or the amine salts will decompose.
4. Concentrations of 500 mg/l volatile acids could be detected.
5. Samples of pure salts gave R_f values checking well with those reported in the literature.

6. "Sour" cultures gave distinct multiple spots indicating the presence of more than one acid.

7. Digester overflow liquor of 36 mg/l volatile acids content gave no spot above the point of application.

8. A 1-per cent solution of the BCG gave better results than the 2-per cent of Hiscox and Berridge.

9. An especially designed atomizer giving a fine spray or mist is essential for the application of the indicator (BCG).

10. The size of the eluate spots does not bear a simple relation to concentration.

Test of Reagents

Five strips of Whatman No. 1 paper suspended so as to dip in the eluent in the usual manner for ascending elution for 18 hr were then dried and sprayed with the BCG. No alkaline spots or zones developed which indicated impurities in the reagents or paper. Fingerprints developed in blue where the paper was purposely touched. A second set of six strips was carried through the usual procedure in the descending elution chamber. These showed no spots or zones on spraying with the indicator, thus confirming the purity of the reagents.

Interfering Substances in Low Acid Overflow Liquor

Ten strips spotted in replicate with 0.01 ml of overflow liquor taken from two digesters showed only the original spot on development with BCG. These samples were known to contain less than 100 mg/l volatile acids.

Three samples of overflow liquor containing less than 100 mg/l volatile acids were brought to 1,000 mg/l volatile acids equivalence with standard sodium acetate solution. These were set up in triplicate and eluted and developed in the usual manner along with a control of sodium acetate in distilled water, equivalent to 1,000 mg/l volatile acids. All 9 checked the control in R_f value and size of spot.

Comparison of Ascending, Descending, and Horizontal-Centrifugal Elutriation

A comparison of separation of the volatile acids spot from the original spot, i.e., the spot at the point of application of the sample, showed no advantage in the descending method. In some 50 strips developed by the ascending method the eluent front was 120 to 130 mm from the starting line after 4 hr elution while in the same number of tests by the descending method the eluent front was about 140 mm from the starting line in the same time and R_f values checked satisfactorily. The apparatus for the ascending method is simpler and less expensive. In the experiments reported here the chamber for descending chromatography was relatively large and hence it was difficult to maintain saturation of the atmosphere with the eluent vapor (11).

Extensive experiments with a device for carrying out horizontal-centrifugal elution were unsuccessful due apparently to the eluent feed which was controlled by a small orifice (0.003 to 0.005 in.). Surface tension effects interrupted the flow. A fine capillary jet for eluent feed seems to work satisfactorily (8). Centrifugal elution, when successful, is reported to be complete in 5 to 10 min. The cost of the apparatus is a minimum of $250.00.

Sensitivity

As noted above, overflow liquor samples showing less than 100 mg/l volatile acids showed no volatile acids spot on the chromatogram. To test the sensitivity at higher concentrations the following experiment was carried out: To samples of the three overflow liquors previously showing blanks, standard NaAc was added to give an equivalent HAc concentration of 600 mg/l. These were spotted in triplicate respectively with 0.01 ml of sample on 9 strips of

paper together with one strip spotted with 0.01 ml NaAc of the same concentration. All were elutriated by the descending procedure for six hours, dried, and sprayed with BCG. All strips gave well-defined spots on development. The R_f values for the overflow liquor samples varied from 0.20 to 0.23 and the R_f value for the NaAc in distilled water was 0.23. This is considered good agreement. Four separate tests at 600 mg/l volatile acids with NaAc in distilled water gave well-defined spots on development but at 450 mg/l volatile acids and below, distinct spots failed to develop or were fleeting, fading after 30 to 60 seconds. This fading was attributed in part to a higher than recommended concentration of the developing indicator (2 per cent). A 1-per cent solution gave better results and was used in subsequent work.

Seventeen strips spotted with either NaAc or $CaAc_2$ equivalent to 1,000 mg/l all showed good spots with proper R_f for acetic. The one failure was known to be due to an eluent which was diluted too much. Eleven strips run at 500 mg/l HAc equivalent concentration also showed good spots on development with BCG. The one failure at this concentration was from the same run reported immediately above as a failure. Seven strips spotted with acetate below 500-mg/l HAc equivalence failed or gave very fleeting spots.

From these controlled experiments it was concluded that the method can be relied on to give a positive test with volatile acid concentrations of 500 mg/l HAc equivalence or higher and that there are no interfering substances in the digester liquors tested.

Acid Overflow Liquors

Five samples of acid overflow liquors from experimental tanks, together with the volatile acid content as de-

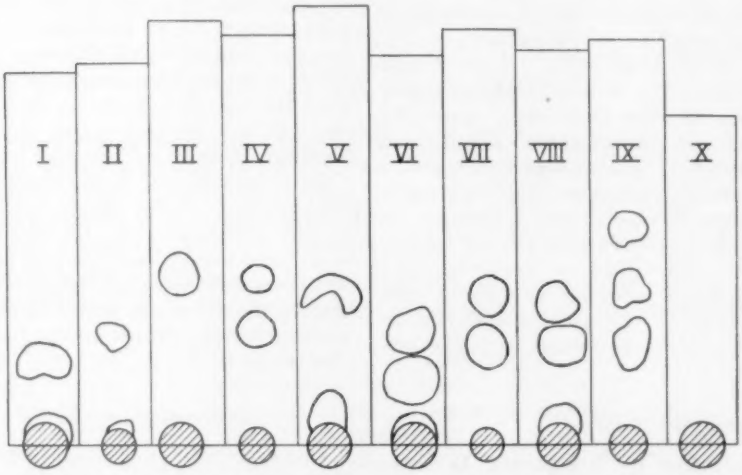


FIGURE 1.—An example of chromatograms. The bottom line indicates where the sample was applied. The top lines represent the height to which the eluent rose (eluent front); I, overflow liquor, 0.010 ml $CaAc_2$, 1,000 mg/l volatile acids equivalence; II, overflow liquor, 0.005 ml $CaAc_2$ as in I; III, 0.010 sodium propionate, 1,000 mg/l volatile acids equivalence; IV, 0.005 ml laboratory sample, 550 mg/l volatile acids; V, 0.010 laboratory sample, 700 mg/l volatile acids; VI, 0.010 ml laboratory sample, 726 mg/l volatile acids; VII, 0.005 ml laboratory sample, 1,600 mg/l volatile acids; VIII, 0.005 ml laboratory sample, 3,500 mg/l volatile acids; IX, 0.005 ml Rumen Fluid; X, 0.01 ml overflow liquor, <100 mg/l volatile acids.

termined by "Standard Methods" procedure were used. The chromatograms from these samples were developed by the procedure described above.

A well-defined round blue spot appears at the point of sample application and is due to inorganic alkaline substances (e.g., Na_2CO_3) not eluted. A light blue is sometimes seen at the upper edge of this spot due, presumably, to a "creeping" of inorganics. The location of the amine salts of the volatile acids appears as light blue areas on spraying with the BCG. Since the colors fade and the orange background becomes green on standing the developed spots are promptly outlined in pencil. Tracings of these chromatograms together with those from certain synthetic solutions are shown in Figure 1.

From a study of Figure 1, it is apparent that at less than 100 mg/l volatile acids no evidence of volatile acids appears but that at 600 mg/l and above such evidence clearly appears. Presence of both acetic and propionic acids is indicated by R_f values in strips IV, VI, VII, and VIII. Larson and Mueller (12) report acetic and propionic in sour tank liquor tested by column chromatography. Hindin and Dunstan (13) also report acetic and propionic. The appearance of strip V is cause for speculation. However, it clearly shows a positive test for volatile acids. The third or upper spot on strip IX is identified as butyric from its R_f value. Irregular shapes may be attributed to variations in paper texture.

Quantitative Factors

As noted by Hiscox and Berridge (10), attempts have been made to relate the size of the spot with the amount or concentration of the unknown but the authors have failed to find any such simple relation. In the work reported here, it has been observed that at 600 mg/l or above the spot appears within one minute and is permanent for a half hour or more. At lower concentrations the spot develops more slowly or not at all. At higher concentrations the color is deeper and the spot somewhat larger. For a general discussion of the quantitative interpretation of Cg's the reader is referred to Block *et al.* (11).

Summary

A chromatographic method for detecting volatile acids in anaerobic digesters at 600 mg/l has been described. The method also shows the presence of propionic and butyric acids when they occur along with acetic. This is not accomplished by distillation methods except by adopting elaborate procedures. Data on the presence of propionic and butyric acids may be highly important in controlling digesters (13).

Unless or until the chromatographic method is developed to a precise quantitative procedure, distillation methods will still be required for dealing with serious acid conditions. For frequent monitoring of digesters, especially at times when abnormal conditions threaten the operation, the simpler and less time-consuming chromatographic method will be most useful.

Variations in the composition and concentration of the eluent and improved standardization of the technique offer good possibilities of developing a quantitative method along the lines of the procedure described above. These are under consideration for future study.

Acknowledgments

This work was supported in part by NIH Grant RG 4595 and in part by the Pacific Flush Tank Co.

Samples of acid overflow liquors from experimental tanks and volatile acids determinations were obtained from the Phelps Laboratory through the courtesy of Professor F. W. Gilcreas and Mr. G. B. Morgan.

References

1. "Standard Methods for the Examination of Water, Sewage and Industrial Wastes." p. 347, 10th Ed., Amer. Pub. Health Assn., New York (1955).
2. Buswell, A. M., and Neave, S. L., "Laboratory Studies of Sludge Digestion." Ill. State Water Survey Bull. 30, p. 76 (1930).
3. Sawyer, C. N., "Chemistry for Sanitary Engineers." p. 341, McGraw-Hill Book Co., New York (1960).
4. Buswell, A. M., *et al.*, "Anaerobic Fermentations." Ill. State Water Survey, Bull. 32, p. 59 (1936).
5. Mueller, H. F., Buswell, A. M., and Larson, T. E., "Chromatographic Determination of Volatile Acids." *Sewage and Industrial Wastes*, **28**, 3, 255 (Mar. 1956).
6. Mueller, H. F., Larson, T. E., and Lennarz, W. J., "Chromatographic Identification and Determination of Organic Acids in Water." *Anal. Chem.*, **30**, 41 (1958).
7. James, A. T., and Martin, A. J. P., "Gas Liquid Partition Chromatography: the Separation and Microestimation of Volatile Fatty Acids from Formic Acid to Dodecanoic Acid." *Biochem. Jour.*, **50**, 679 (1951–52).
8. Duncan, R. E. B., and Porteous, J. W., "The Identification of the Lower Straight-Chain Fatty Acids by Paper Partition Chromatography." *Analyst*, **78**, 641 (1953).
9. Reid, R. L., and Lederer, M., "Separation and Estimation of Saturated C_2–C_7 Fatty Acids by Paper Partition Chromatography." *Biochem. Jour.*, **50**, 60 (1951–52).
10. Hiscox, E. R., and Berridge, N. J., "Use of Paper Partition Chromatography in the Identification of Volatile Fatty Acids." *Nature*, **166**, 522 (1950).
11. Block, R. J., Durrum, E. L., and Zweig, G., "Paper Chromatography and Paper Electrophoresis." 2nd Ed., p. 90, Academic Press, New York (1958).
12. Larson, T. E., and Mueller, H. F., Private Communication.
13. Hindin, E. and Dunstan, G. H., "Some Aspects of Sludge Digestion." *Water and Sewage Works*, **106**, 457 (1959).

USPHS TRAINING COURSES

The Public Health Service has announced a series of training courses and meetings to be held at the Robert A. Taft Sanitary Engineering Center in Cincinnati. These are available to those having the special interests and qualifications described in the course outlines.

The courses and outlines are as follows:

Aug. 15–19	Recent Developments in Water Bacteriology
Aug. 29–31	Water Quality Measurement and Instrumentation Symposium
Oct. 3–14	Basic Radiological Health
Oct. 17–21	Radionuclide Protection
Oct. 17–21	Radiological Health for X-ray Technicians
Oct. 24–28	X-ray Protection
Oct. 24–Nov. 4	Plankton Analysis

Applications and further information may be obtained from the Chief, Training Program, Robert A. Taft Sanitary Engineering Center, 4676 Columbia Parkway, Cincinnati 26, Ohio, or to a PHS Regional Office Director.

FLOW EQUATIONS FOR SEWAGE SLUDGES *

By Vaughn C. Behn

Associate Professor of Civil Engineering, University of Delaware, Newark, Del.

Since the sanitary engineer has always had a justifiable interest in the hydraulics of the various components of the sewage treatment process, it is not surprising that his investigations have included the pipeline transportation of sewage sludges. However, the finer points of head-loss computation seem to have aroused less interest than the important maintenance problem, despite the fact that the piping of sludges for long distances is not a rare event (1).

As a result, rule-of-thumb methods for sizing pipelines seem to prevail despite the fact that more sophisticated methods have been made available in other fields for fluids at least as complex as sewage sludge.

The full use of these methods requires laboratory investigation until such time as sufficient experience is gained in the application of the methods. This paper has been prepared as a review of the technology of flow of non-Newtonians, with special emphasis on sewage sludge.

A non-Newtonian is defined on the basis of failure to obey Newton's equation of viscosity in laminar flow. That is, a simple proportionality does not exist between shear stress and shear rate. The technique for analyzing the pipeline flow of non-Newtonians may be based on the shear stress-shear rate relationships which do exist, or on completely unspecified relationships.

In any case, the study of non-Newtonians usually involves at least two flow parameters. This is in contrast to a Newtonian such as water which is specified by one flow parameter, the viscosity. For both Newtonians and non-Newtonians, the flow parameters are determined experimentally by the use of viscometers. In this report, special attention is given to the capillary and rotational viscometers, the latter restricted to the type which has an inner bob and an outer rotating cup. These two types of viscometers are now recognized as yielding equivalent basic data on flow properties.

For those non-Newtonians whose flow characteristics are independent of time, a variety of techniques is available to make pressure drop calculations. Essentially, the procedures parallel those used with Newtonians. For example, generalized Hagen-Poiseuille and Reynolds Number equations may be found which actually reduce to the more familiar Newtonian form as a special case.

These equations take varying form depending on the basic mathematical model used to define the shear stress-shear rate relationship. Equations of a generalized nature have also been derived which are not predicated on a particular mathematical model.

In general, it may be said that the procedures parallel those available for Newtonians such as water, except that the question of pipe roughness is less fully developed and, perhaps, less important in a practical sense.

History of Investigations

Possibly the first important investigation in this country concerning the problem of computing head loss in pipelines used to carry sewage sludge

* Presented at the 32nd Annual Meeting, Federation of Sewage and Industrial Wastes Assns.; Dallas, Tex.; Oct. 12–15, 1959.

was reported in 1929 (2). In addition to certain experimental work, this report analyzed all available data and concluded that sludge behaves more like water at high velocities, but that in general no law of flow could be found. In a discussion of this report Clifford (3) dissented, claiming that the committee "builded better than they knew." Clifford recommended that further work be done on the physical qualities of sludges with the objective of utilizing a friction factor-Reynolds Number plot. In 1938 Hatfield (4) attempted to enlarge on Clifford's suggestion, supporting his work by extensive experimentation with a rotational viscometer. This work was limited by the choice of a single flow property, the apparent viscosity. Nevertheless, his work is an important early contribution to the flow properties of sewage sludges.

Credit for the first actual attempt to use a generalized flow equation in connection with sewage sludge must go to Merkel (5). In this work, there is the first recognition of viscometric work as related to the sizing of pipelines used to carry sewage sludge. However, the work does leave the impression that the value of the viscometric analysis is as a qualitative guide to friction losses in actual piping situations. This was probably not an unreasonable conclusion for the time.

While Merkel first recognized the value of the application of the scientific work being done in the field of rheology, it remained for Babbitt and Caldwell (6) to make the first quantitative application of the science of rheology to the engineering problem of transporting sewage sludges. Not only has this classic study remained the basis for current sanitary engineering textbook treatment of this subject (7) (8), but it is also an important paper in the entire non-Newtonian field because of basic ideas introduced concerning the onset of turbulence (9).

Since the publication by Babbitt and Caldwell, much progress has been made generally in the approach to sizing of pipelines for carrying non-Newtonians (9). Generally, however, this progress does not seem to have received critical notice in the sanitary engineering literature. Some experimental work has been reported without reference to basic flow characteristics (10) (11), and Wirts (12) has presented a particularly interesting study of the basic problem of pumping sludges for long distances. Papers enlarging on the work of Babbitt and Caldwell seem to be limited to that of Chou (13), while no source has been located which takes advantage of the number of issues clarified since Babbitt and Caldwell's study.

Classification of Fluid Behavior

Ideal Fluid

An ideal fluid is one which offers no resistance to tangential shearing forces. That is, there is no friction involved. Even when an ideal fluid is in motion, the forces at any internal section are all normal to the section. Thus, all forces in an ideal fluid are pressure forces.

These facts are best illustrated by a hypothetical experiment (since an ideal fluid does not exist in reality). The

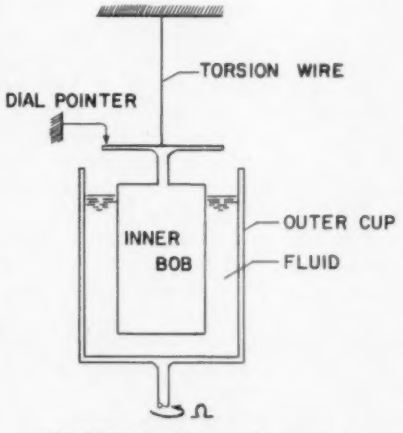


FIGURE 1.—Rotational viscometer.

TABLE I.—Shear Stress—Shear Rate Relationships

Fluid	Relationship Stress-Rate	Apparent Viscosity (μ_a)
Perfect	$\tau = 0$	0
Newtonian	$\tau = \mu\left(\frac{du}{dy}\right)$	μ
Bingham Plastic	$\tau - \tau_y = \eta\left(\frac{du}{dy}\right)$	$\frac{\tau_y}{\left(\frac{du}{dy}\right)} + \eta$
Pseudo-plastic	$\tau = K\left(\frac{du}{dy}\right)^n$	$K\left(\frac{du}{dy}\right)^{n-1}$
Any time-independent fluid	$\tau = F\left(\frac{du}{dy}\right)$ or $\frac{du}{dy} = G(\tau)$	$\frac{F\left(\frac{du}{dy}\right)}{\left(\frac{du}{dy}\right)}$ or $\frac{\tau}{\left(\frac{du}{dy}\right)}$

fluid is enclosed between the cup and the bob in a rotational viscometer similar to that shown in Figure 1. The outer cup is supported and is rotated at an angular velocity Ω. Since there is no resistance to shear, the dial attached to the inner bob will not move and will, therefore, show no deflection. The shear stress is zero as noted in Table I.

Newtonian Fluids

An entirely different result is obtained when the experiment is repeated with any real fluid. With a constant fluid temperature and cup speed, the inner bob will eventually come into equilibrium in a position deflected from the original. This deflection, when within the elastic limits of the torsion wire, is proportional to a torque, which is, in turn, proportional to the shear stress within the fluid.

For any real fluid, then, a shear stress exists, and this is a function of shear rate. Experiments with a large group of low molecular weight liquids, including water, have demonstrated that in laminar flow this relationship is a simple proportionality as shown in Table I for a Newtonian liquid. The constant of proportionality is a measure of resistance to deformation, and is known as the viscosity. Those fluids whose behavior is specified by the equation are known as Newtonians.

Non-Newtonian Fluids

1. Time-independent non-Newtonians. For many fluids in laminar flow the simple proportionality between shear rate and shear stress does not exist. These fluids are, therefore, classified as non-Newtonians. A further classification of non-Newtonians may be made on the basis of whether or not the relationship between shear stress and shear rate is independent of time.

For time-independent non-Newtonians the relationship between shear stress and shear rate is best denoted on an arithmetic plot as in Figure 2. In this figure, three types of non-Newtonians are shown in contrast to a Newtonian. The category which most closely resembles Newtonian flow is that of the Bingham Plastic. The difference is that fluid movement is not initiated until a yield value of shear stress is overcome. This type of behavior is easily expressed mathematically as shown for the Bingham Plastic in Table I.

Possibly the greatest number of non-Newtonians belong to that group of fluids whose behavior is noted in Figure 2 as pseudoplastic. For a large number of pseudoplastics, the data from Figure 2 will plot as a straight line on log-log paper. When this is so, the relationship between shear stress and shear rate is given by a power function of the type shown for pseudoplastic in Table I. Still another class of non-Newtonians, the dilatant fluids, exhibits a behavior which is opposite to that of the pseudoplastic fluids. The dilatant fluids are of less importance commercially (9), and apparently do not appear in waste treatment. The relationship between shear stress and shear rate for dilatant fluids is also noted in Figure 2.

For analysis it is sometimes con-

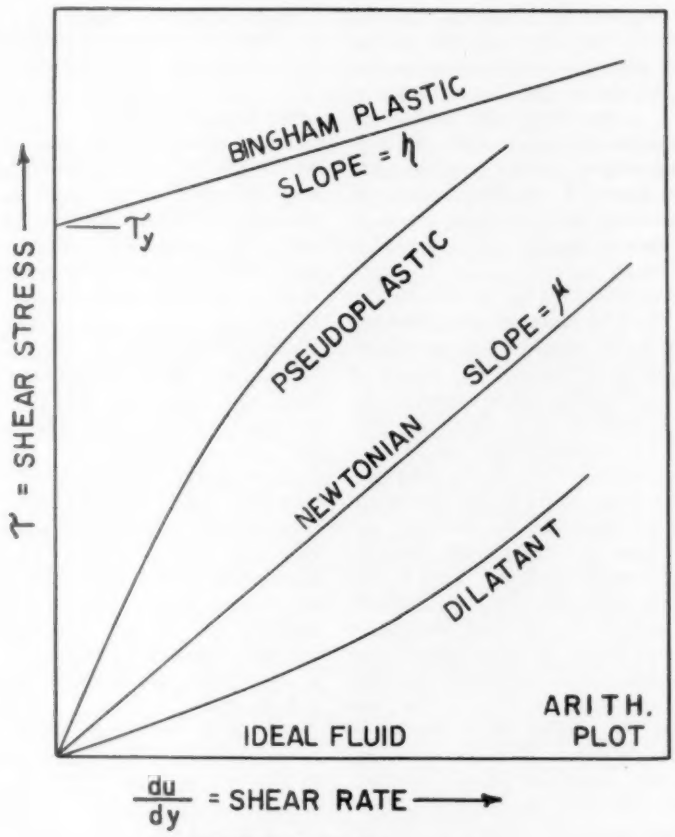


FIGURE 2.—Fluid flow curves.

venient not to attempt to define the relation between shear stress and shear rate except to say merely that one is a function of the other. This is indicated for any time-independent fluid in Table I.

2. Time-dependent non-Newtonians. Occasionally fluids exhibit a shear rate which is not constant with fixed shear stress and temperature. When this behavior is reversible, and the slope of the flow curve of the type shown in Figure 2 decreases with time, the material is said to be thixotrophic. A less common phenomenon involves virtually the opposite of this behavior which classifies the liquid as a rheopectic fluid.

Occasionally thixotrophy has been erroneously accredited to Bingham Plastics with high yield stresses (14). Also, there are reported instances where experimental errors have led falsely to the conclusion that thixotrophy was present (9). Possibly in the final analysis thixotrophy is closely related to pseudoplasticity with the presence of a time lag in the development of pseudoplastic properties (9).

3. Apparent viscosity. Occasionally workers in the field of rheology find it convenient to utilize the apparent viscosity, which is defined as the ratio of shear stress to shear rate. For a Newtonian it is evident that the apparent viscosity is the true viscosity. For

non-Newtonians the apparent viscosity will usually involve two flow parameters, as may be seen by inspection of the equations in the last column of Table I. The implication of these equations has been noted by Metzner (9), who states that the term viscosity is meaningless for non-Newtonians unless the shear rate or shear stress to which this viscosity is referred is stipulated.

4. Sewage sludge as a non-Newtonian. The literature on non-Newtonians in general classifies sewage sludge as a Bingham Plastic. The origin of this categorization is apparently the work of Babbitt and Caldwell (6). The flow equations presented in that work are all based on plastic behavior. One interesting factor is that literature not written especially for sanitary engineers does not distinguish between types of sewage sludges. This is not surprising, since Babbitt and Caldwell do not accentuate the fact that their conclusions were based primarily on experiments with digested sludges. Testing of activated sludges was limited, and the results were similar to those for water. Raw or primary sludges also received limited testing, and were analyzed as Bingham Plastics. Nevertheless, it might be unwise to project the limited results on raw sludges to any implied conclusion. In this respect, one might note that British practice leans toward pipeline transportation in digested rather than raw form, although this may be in great part due to a desire to avoid clogging (15).

The work of Merkel (5) also tends to support the contention that sewage sludges are Bingham Plastics, since he, too, was interested in applying the type of analysis predicated on plastic flow behavior. Merkel did not test activated sludges, but did find a difference between digested and partly digested sludges in his viscometer data.

Hatfield's viscometric data, which were collected on unstirred samples, show a Bingham Plastic-like behavior for both raw and digested sludges (4). He also found that activated sludges were more Newtonian in behavior than other sewage sludges.

All of these workers were concerned with evidences of thixotrophy, although only Hatfield gives any substantial quantitative data. Babbitt and Caldwell took special precautions to eliminate thixotrophic effects, and in Merkel's work the discrepancy due to thixotrophy was not great. Later Wolfs attempted to determine the thixotrophic effect in actual pumping tests and concluded that it was significant only at very low velocities (10).

In summary, the weight of evidence seems to indicate a Bingham Plastic behavior for digested sewage sludges. However, the possibility of pseudoplastic and even some thixotrophic behavior also exists. The same might be said for raw sludges although this is less well supported. Activated sludge is apparently much more Newtonian in behavior.

The need for much more experimental testing is more than apparent. In this respect the influence of such variables as gas content, concentration, etc., is indeed very little known. These factors may be of importance in causing an apparent thixotrophy.

Capillary Viscometer

General

The capillary viscometer has been used with some success for obtaining basic information on the flow properties of non-Newtonians. The experimental work is applied to equations which demonstrate the laminar flow behavior of the fluid in the capillary. For convenience some of the useful equations have been tabulated in Tables II and III. Not all of these equations have actual utility, but they are included for the purpose of increasing the general understanding of the more useful equations.

TABLE II.—Shear Stress—Shear Rate Relationship for Capillary Viscometer

Fluid	Relationship
Newtonian	$\tau = \mu\left(-\frac{dv}{dr}\right)$
Bingham Plastic	$\tau - \tau_y = \eta\left(-\frac{dv}{dr}\right)$
Pseudoplastic	$\tau = K\left(-\frac{dv}{dr}\right)^n$
Any time-independent fluid	$G(\tau) = \left(-\frac{dv}{dr}\right)$

The column of equations in Table II lists the shear stress–shear rate relationship in a conduit. These equations are, of course, particular applications of the last four equations in Table I. The first column in Table III lists the relationship between $8V/D$ and the shear stress at the pipe wall, τ_w. τ_w is directly related to pressure drop and, furthermore, should not change with constant $8V/D$.

When the fluid is a Newtonian, $8V/D$ is actually the shear rate at the wall, as may be seen in the second column of Table III. This is not true with non-Newtonians, but a relationship may be derived as indicated by the listing of equations.

One other aspect of these equations is that they permit an interpretation of the quantities K, K', n, and n'. Inspection of the equations in the first column of Table III reveals that if $n = n' = 1$ and $K = K' = \mu$ then the equations for a pseudoplastic fluid and any time-independent fluid reduce to a Newtonian fluid. Therefore, n and n' represent the departure from Newtonian flow, while K and K' represent a resistance to flow. For this reason n and n' have been termed flow-behavior indexes, while K and K' are termed flow consistency indexes (9).

Derivation of Equations

The technique for developing laminar flow equations for application to the capillary viscometer are similar regardless of the fluid. While it is not the purpose of this paper to demonstrate the solution of all equations given, the general procedure may be of interest. References are given in the tables which have been found useful in reconstructing the equations.

The first step in the procedure is to obtain the general relationship for shear stress versus shear rate in a form specific for a circular conduit. This has been done, for example, in Table II. The resulting differential equation is then solved for the point velocity v in terms of the radial distance r at any point in the conduit.

To accomplish this solution, the relationship between the two unknowns,

TABLE III.—Laminar Flow Equations—Capillary Viscometer

Fluid	Relationship between τ_w* and $8V/D$	Expression for $(-dv/dr)_w$
Newtonian	$\frac{8V}{D} = \frac{\tau_w}{\mu}$	$\frac{8V}{D}$
Bingham Plastic (6) (9) (16)	$\frac{8V}{D} = \frac{\tau_w}{\eta}\left[1 - \frac{4}{3}\frac{\tau_y}{\tau_w} + \frac{1}{3}\left(\frac{\tau_y}{\tau_w}\right)^4\right]$	$\left[\frac{8V}{D\left[1 - \frac{4}{3}\frac{\tau_y}{\tau_w} + \frac{1}{3}\left(\frac{\tau_y}{\tau_w}\right)^4\right]} - \frac{\tau_y}{\eta}\right]$
Pseudoplastic (9) (17)	$\tau_w = K\left(\frac{3n+1}{4n}\right)^n\left(\frac{8V}{D}\right)^n$	$\frac{8V(3n+1)}{4Dn}$
Any time-independent fluid (9) (18) (19)	$\tau_w = K'\left(\frac{8V}{D}\right)^{n'}$†	$\frac{8V(3n'+1)}{4Dn'}$

* $\tau_w = \frac{D\Delta P}{4L}$. † $n' = \frac{d(\ln \tau_w)}{d\left(\ln \frac{8V}{D}\right)}$.

TABLE IV.—Form of Hagen-Poiseuille Equation for Laminar Flow in Capillary

Fluid	Equation
Newtonian	$\frac{\Delta P}{L}=\frac{32\mu V}{D^2}$
Bingham Plastic*	$\frac{\Delta P}{L}=\frac{32\eta V}{D^2}\left[1+\frac{\tau_y D}{V\eta}\right]$
Pseudoplastic (20)	$\frac{\Delta P}{L}=V^n\left[\frac{6n+2}{n}\right]^n\frac{4K}{D^{(n+1)}}$
Any time-independent fluid (6)	$\frac{\Delta P}{L}=\frac{32V^{n'}K'8^{(n'-1)}}{D^{(n'+1)}}$

* Equation derived by neglecting last term of equation for Bingham Plastic in second column of Table III.

shear stress and radial distance, must be found. This is accomplished by making an equilibrium force balance on a cylindrical element of fluid.

$$\tau(2\pi r)L=\Delta P\pi r^2 \quad \text{or} \quad \tau=\frac{r\Delta P}{2L} \ldots (1)$$

The last equation in Table III is, of course, a particular application of Equation 1.

When the point velocity has been found, an equation involving the mean velocity V is obtained by substitution in the following equation.

$$V\frac{\pi D^2}{4}=\int_0^{r_w} v(2\pi r)dr \ldots\ldots (2)$$

After the double integration described, equations of the type listed in the first column of Table III are found by algebraic manipulation which usually involves reintroduction of Equation 1. This procedure results in the relatively simple equation for a Newtonian. While this particular equation is not familiar, it leads directly to the familiar Hagen-Poiseuille equation. When the original differential equation is more complex, the results of the double integration will usually be more complex as in the case of the equation for the Bingham Plastic. This will be recognized as the Buckingham equation made familiar by Babbitt and Caldwell (6).

Forms of Hagen-Poiseuille Equation

Modified forms of the Hagen-Poiseuille equation may be easily obtained by combining the last equation in Table III with any of the equations of the first column in the same table. The results as listed in Table IV are therefore of use, subject only to the requirement of laminar flow.

Rotational Viscometer

General

A device which is generally considered equivalent to the capillary viscometer is the rotational viscometer. Discussion of this type of viscometer will be limited to the type which has stationary bob and rotating cup as depicted in Figure 1.

The equations developed to study the flow in a rotational viscometer are specific for that viscometer and, of course, may not be applied directly to flow in pipes (as is the case with the capillary viscometer). However, flow parameters obtained from rotational viscometers may be used in pipeline calculations.

For convenience, the flow equations have been tabulated in Tables V and VI. Table V gives the shear stress-shear rate relationship in a concentric viscometer, while the first column of Table VI gives the viscometer flow equation for different types of behavior. In the second column of Table VI are listed the various equations by

TABLE V.—Shear Stress—Shear Rate Relationship for Rotational Viscometer

Fluid	Relationship
Newtonian	$\tau=\mu R\left(\frac{d\omega}{dR}\right)$
Bingham Plastic	$\tau=\tau_y+\eta R\left(\frac{d\omega}{dR}\right)$
Pseudoplastic	$\tau=K\left(R\frac{d\omega}{dR}\right)^n$
Any time-independent fluid	$\left(R\frac{d\omega}{dR}\right)=G(\tau)$

TABLE VI.—Laminar Flow Equations for Rotational Viscometer
(Bob stationary, cup rotating)

Fluid	Flow Equation	Expression for Shear Rate at Bob, $\left(\frac{dv_R}{dR}\right)_1^*$
Newtonian	$\Omega = \frac{M}{4\pi\mu}\left[\frac{1}{R_1^2} - \frac{1}{R_2^2}\right]$	$\frac{M}{2\pi\mu R_1^3}$
Bingham Plastic (16) (17)	$\Omega = \frac{M}{4\pi\eta}\left[\frac{1}{R_1^2} - \frac{1}{R_2^2}\right] - \frac{\tau_y}{\eta}\ln\left(\frac{R_2}{R_1}\right)$	$\left[\frac{M}{2\pi\eta R_1^3} - \frac{\tau_y}{\eta}\right]$
Pseudoplastic (16) (17)	$\Omega = \left(\frac{M}{2\pi K}\right)^{1/n}\left(\frac{n}{2}\right)\left[\frac{1}{R_1^{2/n}} - \frac{1}{R_2^{2/n}}\right]$	$\frac{2\Omega}{n[1-(R_1/R_2)^{2/n}]}$
Any fluid (20) (21)	$\Omega = \frac{G(\tau_1)\ln S}{\left[1 + m\ln S + \frac{m^2(\ln S)^2}{3} + \frac{(\ln S)^3}{3}\cdot\frac{dm}{d(\ln\tau_1)} + \cdots\right]}$ †	$\frac{\Omega}{\ln S\left[1 + m\ln S + \frac{m^2(\ln S)^2}{3} + \frac{(\ln S)^3}{3}\cdot\frac{dm}{d(\ln\tau_1)} + \cdots\right]}$

* $\frac{dv_R}{dR} = R\frac{d\omega}{dR}$ † $S = \frac{R_2}{R_1}$; $m = \frac{1}{n}$; $n = \frac{d(\ln\tau_1)}{d(\ln\Omega)}$.

which the shear rate at the bob may be calculated.

Derivation of Flow Equations

The starting point in the development of the equations for the rotational viscometer is the equation which defines shear stress-shear rate relationship. In this case the final equations involve a single integration, usually in terms of the cup speed Ω. The solution requires that the relation between shear stress τ and radial distance R be found. This is accomplished by an equilibrium force balance. This technique was used previously to obtain Equation 1, but now a cylindrical section is taken whose radius R is greater than that of the bob but less than that of the cup.

$$M = \tau(2\pi Rl)R \quad \text{or} \quad \tau = \frac{M}{2\pi R^2 l} \quad . \quad (3)$$

The equations in the first column of Table VI are the results of the integration of the differential equations listed in Table V. In the case of the equations in Table VI for a pseudoplastic fluid and any fluid it is also necessary to ascertain the relationship for n given in Equation 3. This latter equation is developed in connection with analysis of fluids of unspecified shear stress-shear rate relationships.

Of interest is the fact, demonstrated by Rankin (22), that the equation for a pseudoplastic is equivalent to that for any fluid, when the last term in the brackets in the latter is omitted.

Transition from Laminar to Turbulent Flow

General

With Newtonians, the accepted method for determining whether laminar or turbulent flow exists is by calculation of the Reynolds Number. Furthermore, pressure drops can be calculated by entering into established plots of Reynolds Number versus friction factor. When applicable, rough-

TABLE VII.—Pressure Drop, Reynolds Number, and Friction Factor Relationships

Fluid	Pressure Drop	Reynolds Number	Fanning Friction Factor*
Newtonian	$\frac{\Delta P}{L}=\phi(D, V, \rho, \mu)$	$N_{Re}=\frac{VD\rho}{\mu}$	$f=\frac{16}{N_{Re}}$
Bingham Plastic (9)	$\frac{\Delta P}{L}=\phi(D, V, \rho, \eta, \tau_y)$	$N_{Re}=\frac{VD\rho}{\eta}$	$\frac{1}{N_{Re}}=\frac{f}{16}-\frac{N_{He}\dagger}{6N_{Re}^2}+\frac{1}{3f^2}\cdot\frac{N_{He}^4}{N_{Re}^8}$
Pseudoplastic	$\frac{\Delta P}{L}=\phi(D, V, \rho, K, n)$	$N_{Re}=\frac{8V^{(2-n)}D^n\rho}{K\cdot\left[\frac{6n+2}{n}\right]^n}$	$f=\frac{16}{N_{Re}}$
Any time-independent fluid (9)	$\frac{\Delta P}{L}=\phi(D, V, \rho, K', n')$	$N_{Re}=\frac{D^{n'}\rho V^{(2-n')}}{K'8^{(n'-1)}}$	$f=\frac{16}{N_{Re}}$

* N_{Re} is that given on same line in previous column.

† N_{He} = Hedstrom Number = $\frac{\tau_y D^2\rho}{\eta^2}$.

ness coefficients are utilized on these same plots.

Non-Newtonians such as sewage sludge may be analyzed on somewhat the same basis, as suggested by Clifford (3) many years ago. Techniques for accomplishing this have much improved, especially in recent years. However the analogy at present does not extend to flow in rough pipes. Roughness may not be as important as with Newtonians, although this point needs further clarification. In any case, this discussion of non-Newtonians will be limited to flow in smooth pipes.

Modified Reynolds Number

Modified Reynolds Numbers may be determined for all time-independent non-Newtonians, regardless of whether or not the shear stress-shear rate relationship is specified. To illustrate this, Reynolds Numbers for various conditions have been tabulated in the second column of Table VII.

Only one non-Newtonian, the Bingham Plastic, is analyzed in a manner which is directly analogous to the dimensional reasoning used with Newtonians. When dimensional reasoning is applied to a Bingham Plastic, the friction factor is observed to be a function of two dimensionless groups, the Reynolds and Hedstrom Numbers. The actual relation between the Fanning friction factor, and these two numbers is given in the third column for Bingham Plastic in Table VII. This equation is another form of the equation shown in Table III for Bingham Plastic.

The Reynolds Number for pseudoplastic flow is determined by comparing the usual relationship between Reynolds Number and fraction factor in laminar flow with the modified Hagen-Poiseuille equation in Table IV. This same procedure is also used to obtain the N_{Re} for fluids whose shear stress-shear rate relationship is unspecified. This latter Reynolds Number, which is given in Table VII for any time-independent fluid has been utilized by Metzner in the analysis of a number of non-Newtonians (9). Metzner has found that laminar flow will usually cease at Reynolds Numbers from 2,100 to 2,800. The lower number is equivalent to a Fanning friction factor of 0.008. Furthermore, the transition zone will extend to a Reynolds Number of 70,000. In this region, Metzner suggests the calculation of the Fanning friction factor by the empirical equation

$$f = 0.00140 + \frac{0.125}{(N_{Re})^{0.32}} \quad \cdots (4)$$

Calculation of Pressure Drop

General

From an engineering standpoint, one of the important aspects of the study of flow properties of non-Newtonians is to be able to make reasonable predictions of pressure drop for given flows and pipe diameters. Several alternative procedures are available for such calculations. The selection of procedure depends on such factors as the type of flow behavior and flow regime.

Laminar Flow

Possibly the most straightforward method for laminar flow is to scale up to plant size from log-log plots of laboratory capillary viscometer data. The actual plot involves $D \Delta P/4L$ versus $8V/D$ and the scale up is made at constant V/D. This procedure is based on the equation in Table III for any time-dependent fluid.

When it must be confirmed that laminar flow exists, it is preferable to use this equation to calculate K' and n'. Then the Reynolds Number can be calculated from the equation for any time-dependent fluid shown in Table VII. When the existence of laminar flow is confirmed, the modified Hagen-Poiseuille equation in Table IV may be utilized to compute pressure drop.

When rotational viscometer data are available, equations specific for this instrument may be utilized to obtain paired values of shear stress and shear rate (at the bob). When these data plots as a straight line on arithmetic paper, the fluid is a Bingham Plastic. When the data plot as a straight line on log-log paper, the material is a power function pseudoplastic. The appropriate flow-behavior indexes can then be taken directly from the plots and used with the modified Hagen-Poiseuille equations. Otherwise, graphical integration is required or the data must be tested in the capillary viscometer.

When it is known that the fluid is a Bingham Plastic or a power function pseudoplastic, it is frequently best to utilize the specific equations for this type behavior. When the fluid behavior is unknown, the best procedure would seem to involve utilization of the equations which do not specify shear rate-shear stress relationship. This latter procedure would seem to be the best approach for sewage sludges until such time as the type of flow behavior has been more explicitly established.

Transient and Turbulent Flow

When transition zone or turbulent flow is expected, the situation clearly suggests calculation of the modified Reynolds Number as given in Table VII for any time-dependent fluid. As noted previously, Metzner has suggested Equation 4 for computing the Fanning friction factor. This may then be used in the conventional manner for computing head loss. When the generalized Reynolds Number is greater than 70,000, fully developed turbulent flow should be present. Since most workers have demonstrated that the conventional procedures used for Newtonians have more validity in turbulent flow, conventional procedure may apparently be followed with reasonable accuracy.

When the fluid is definitely specified as a Bingham Plastic, the unique relationships for such a fluid may be considered. The Reynolds Number as shown in Table VII for a Bingham Plastic and the Hedstrom Number as shown in the same table may be computed. By utilizing a plot of Reynolds Number versus Fanning friction factor as modified by the equation in Table VII for a Bingham Plastic, it is possible to judge simultaneously the flow regime and read off the factor (9). Once again, in highly developed turbulent flow the non-Newtonian behaves more like the Newtonian. The interpretation is then that the Hedstrom

Number is of less significance in turbulent flow, which is verified by the aforementioned plot.

As mentioned earlier, the role of roughness in pipes carrying non-Newtonians in the turbulent flow range is not yet clearly understood. Some strides in the direction of increased understanding of this phenomenon have been made, however (23). The complete solution of this problem will greatly improve the already valuable techniques described for the sizing of pipelines to transport sewage sludges.

Summary and Conclusions

The problem of designing pipelines to carry sewage sludges (like all other transport phenomena in which sludges are involved) involves the fundamental flow properties of the sludges. Like many suspensions and high molecular weight solutions, sewage sludges are not defined with respect to flow behavior unless at least two flow parameters are specified. This characteristic is associated with the departure, under laminar flow conditions, from Newton's simple equation of viscosity, and earns for the material in question inclusion in the category of non-Newtonian fluids.

By definition, therefore, non-Newtonian fluids do not exhibit the straight proportionality between shear stress and shear rate found in laminar Newtonian flow. Also, the single flow parameter, viscosity, which suffices for Newtonians is inadequate for non-Newtonians. The simple equation of viscosity is, therefore, replaced by an equation involving shear rate and shear stress and as stated, at least two flow parameters. The type of behavior encountered dictates the form of the basic shear stress-shear rate equation utilized. This leads in turn to a subclassification of non-Newtonian flow. In this report two types of non-Newtonians, the Bingham Plastic and the pseudoplastic, have been given special attention because of evidence that sewage sludges may be reasonably classified as such.

For these two classifications, mathematical models of the shear stress-shear rate relationships are available. These equations may be integrated for the boundary conditions imposed by capillary and rotational viscometers. The resulting equations contain the basic flow parameters, and thus an avenue is opened for the experimental determination of these parameters. Furthermore, it is possible to derive modified Hagen-Poiseuille and Reynolds Numbers which permit the calculation of pressure drop by the usual techniques.

Most importantly, similar equations can be derived without specifying shear stress-shear rate relationships. The results are, therefore, completely generalized. Due to a relatively broad application with miscellaneous non-Newtonian fluids, some empirical relationships are available between friction factor and generalized Reynolds Number. Therefore, with the aid of viscometry, some estimates can now be made of pressure drops in pipelines used to carry sewage sludges.

With the aid of further research, it may become possible to specify quantitatively the appropriate flow parameters, and demonstrate their modification under different conditions of temperature, solids content, gas content, etc. Such research should prove particularly rewarding, since these flow parameters, as stated, have wide application in the transport phenomena in which sludges are involved.

Acknowledgments

This paper was made possible by a grant of the National Science Foundation for a study of the rheological and settling properties of sewage sludges, and by a grant of the National Institutes of Health, United States Public Health Service, for further examination of the fundamental rheological properties of sewage sludges.

References

1. Wirts, J. J., "Pipe Line Transportation and Disposal of Digested Sludge." *Sewage and Industrial Wastes*, **28**, 2, 121 (Feb. 1956).
2. "Friction of Sewage Sludges in Pipes." Progress Rept. Committee of the San. Eng. Div., *Proc. Amer. Soc. Civil Engrs.*, **55**, 7, 1773 (Sept. 1929).
3. Clifford, W., Discussion of "Friction of Sewage Sludges in Pipes." *Proc. Amer. Soc. Civil Engrs.*, **56**, 4, 821 (Apr. 1930).
4. Hatfield, W. D., "The Viscosity or Pseudo-Plastic Properties of Sewage Sludges." *Sewage Works Jour.*, **10**, 1, 3 (Jan. 1938); *Sewage Works Jour.*, **10**, 2, 272 (Mar. 1938).
5. Merkel, W., "Flow Characteristics of Sewage Sludge and Other Thick Materials." *Physics*, **5**, 355 (Nov. 1934).
6. Babbitt, H. E., and Caldwell, D. H., "Laminar Flow of Sludges in Pipes with Special Reference to Sewage Sludge." Univ. Illinois Bull. **37**, No. 12, 60 pp. (Nov. 14, 1939); and "Turbulent Flow of Sludges in Pipes." Univ. Illinois Bull. **38**, No. 13, 44 pp. (Nov. 19, 1940); *Trans. Amer. Inst. Chem. Engrs.*, **37**, 237 (1941).
7. Fair, G. M., and Geyer, J. C., "Water Supply and Waste-Water Disposal." John Wiley and Sons, Inc., New York (1954).
8. Babbitt, H. E., and Baumann, E. R., "Sewerage and Sewage Treatment." 8th Ed., John Wiley and Sons, Inc., New York (1958).
9. Metzner, A. B., "Non-Newtonian Technology." In "Advances in Chemical Engineering." Edited by T. B. Drew and J. W. Hoopes, Academic Press Inc., New York (1956).
10. Wolfs, J. R., "Factors Affecting Sludge Force Mains." *Sewage and Industrial Wastes*, **22**, 1, 1 (Jan. 1950).
11. Brisbin, S. G., "Flow of Concentrated Raw Sewage Sludges in Pipes." *Jour. San. Eng. Div., Amer. Soc. Civil Engrs.*, **83**, SA3, 1274 (1957).
12. Wirts, J. J., "Sludge Pumping Through Long Force Mains." *Water and Sewage Works*, **95**, 10, 345 (1948).
13. Chou, T., "Resistance of Sewage Sludge to Flow in Pipes." *Jour. San. Eng. Div., Amer. Soc. Civil Engrs.*, **84**, SA5, 1780 (1958).
14. Green, H., "Industrial Rheology and Rheological Structures." John Wiley and Sons, New York (1949).
15. Townend, C. B., "Comments." *Water and Sewage Works*, **95**, 10, 351 (Oct. 1948).
16. Alves, G. E., "Non-Newtonian Flow." In "Fluid and Particle Mechanics." Edited by C. E. Lapple, Univ. Delaware, Newark, Del. (1951).
17. Alves, G. E., Boucher, D. F., and Pigford, R. L., "Pipe Line Design for Non-Newtonians." *Chem. Eng. Prog.*, **48**, 385 (1952).
18. Metzner, A. B., and Reed, J. C., "Flow of Non-Newtonian Fluids-Correlation of Laminar Transition, and Turbulent-Flow Regions." *Jour. Amer. Inst. Chem. Engrs.*, **1**, 4, 434 (Dec. 1950).
19. Mooney, M., "Explicit Formulas For Slip and Fluidity." *Jour. Rheology*, **2**, 210 (Apr. 1930).
20. Krieger, I. M., and Elrod, H., "Direct Determination of Flow Curves of Non-Newtonian Fluids. II. Shearing Rates in the Concentric Cylinder Viscometer." *Jour. Appl. Physics*, **24**, 134 (1953).
21. Krieger, I. M., and Maron, S. H., "Direct Determination of Flow Curves of Non-Newtonian Fluids. III. Standardized Treatment of Viscometric Data." *Jour. Appl. Physics*, **25**, 72 (1954).
22. Rankin, I. S., "Flow of Non-Newtonian Fluids in Rectangular Pipes." Thesis, Univ. Delaware, Newark, Del. (June 1955).
23. Dodge, D. W., "Turbulent Flow of Non-Newtonian Fluids in Smooth Round Tubes." Thesis, Univ. Delaware, Newark, Del. (June 1958).

APPENDIX—NOMENCLATURE

Any consistent set of units may be used. The units specified below are in the English gravitational system:

Nomenclature	Description	Dimension
d	Differential operator	None
$\frac{du}{dy}$	Shear rate in general terms	T^{-1}
$\frac{dv}{dr}$	Shear rate in pipe or capillary	T^{-1}
$\left(\frac{dv}{dr}\right)_w$	Shear rate at wall of pipe or capillary	T^{-1}
$\frac{dv_R}{dR}$	Shear rate in rotational viscometer	T^{-1}
$\left(\frac{dv_R}{dR}\right)_1$	Shear rate at bob in rotational viscometer	T^{-1}
D	Diameter of pipe or capillary	L
f	Fanning friction factor	None
F	Denotes functional relationship	None
G	Denotes functional relationship	None
K	Fluid consistency index for power function pseudoplastics	$\frac{FT^n}{L^2}$
K'	Fluid consistency index for fluids of unspecified shear stress-shear rate relationships	$\frac{FT^{n'}}{L^2}$
l	Equivalent length of viscometer bob	L
L	Length of pipe or capillary	L
m	Inverse of n	None
M	Torque	FL
n	Flow behavior index for power function pseudoplastics	None
n'	Flow behavior index for fluids of unspecified shear stress-shear rate relationship	None
N_{He}	Hedstrom Number	None
N_{Re}	Reynolds Number	None
P	Pressure drop	FL^{-2}
r	Radial distance in pipe or capillary	L
r_w	Radius of pipe or capillary	L
R	Radial distance in rotational viscometer	L
R_1	Radius of bob in rotational viscometer	L
R_2	Radius to cup in rotational viscometer	L
$R\frac{d\omega}{dR}$	Shear rate in rotational viscometer	T^{-1}
S	Ratio of R_2 to R_1	None
u	Local velocity, general	LT^{-1}
v	Local velocity in pipe or capillary	LT^{-1}
v_r	Local velocity in rotational viscometer	LT^{-1}
V	Average velocity in capillary or pipe	LT^{-1}
y	Linear distance	L
η	Coefficient of rigidity of a Bingham Plastic	FTL^{-2}
μ	Coefficient of viscosity of a Newtonian	FTL^{-2}
π	3.1415	None
τ	Shear stress	FL^{-2}
τ_w	Shear stress at capillary or pipe wall	FL^{-2}
τ_y	Mass density	FT^2L^4
ρ	Yield value of shear stress	FL^{-2}
ϕ	Denotes function	None
ω	Angular velocity relative to bob in rotational viscometer	T^{-1}
Ω	Angular velocity of cup relative to bob	T^{-1}

Industrial Wastes

THE SELECTIVE STIMULATION OF RESPIRATION IN MIXED CULTURES OF BACTERIA AND PROTOZOA *

By Nugent Myrick † and A. W. Busch

Respectively, Graduate Assistant and Fellow, and Assistant Professor, Department of Civil Engineering, The Rice Institute, Houston, Tex.

The most important single characteristic from the standpoint of wastewater treatment and water pollution control is the amount of oxygen utilization due to the aerobic action of bacteria and protozoa feeding on the organic constituents of the wastewater. The standard procedure for evaluating this oxygen requirement is the biochemical oxygen demand (BOD) determination.

In 1958, Busch (1) presented a theory stating that the process of biological oxidation of soluble organic substrates involves (*a*) conversion of the substrate into cell substance with varying degrees of synthesis, and (*b*) the utilization of this stored cell material. The latter phase involves both the oxidative organisms and predator organisms such as protozoa. The intent of this investigation was to continue the work initiated by Busch by studying the selective stimulation of respiration and the simultaneous inhibition of assimilation in mixed cultures of bacteria and predator organisms as found in a typical raw sewage used as seed in BOD determinations. The relation between respiration and assimilation is presented diagrammatically in Figure 1.

Recent Work

Inhibitory Studies

Working with the colorless alga, *Prototheca zopfii*, Barker (2) observed an oxygen consumption of only 30 per cent of that theoretically required for the oxidation to carbon dioxide and water of the glucose disappearing from the medium. A similar behavior was observed with other substrates with variations from 50 to more than 80 per cent of the carbon assimilated, depending on the substrate used. Barker concluded, ". . . the process of assimilation of these compounds proceeds in two experimentally distinct stages. The first, which has been called the primary process of assimilation, consists of an oxidative conversion of the substrate into a carbohydrate which is stored in the cells as glycogen. The formation of this carbohydrate is rapid

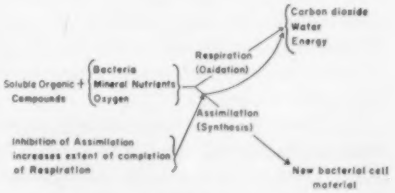


FIGURE 1.—Relation of respiration to assimilation.

* Presented at the 14th Industrial Waste Conf., Purdue University; Lafayette, Ind.; May 5–7, 1959.

† Current address, Department of Civil Engineering, Washington University, St. Louis, Mo.

compared to its subsequent decomposition in the process of cell synthesis which constitutes the second state of assimilation."

Giesberger (3) observed that hydroxy, keto, and dibasic acids as well as the simpler acids and alcohols were not oxidized to completion by the different species of *Spirillum* he studied. In addition, he pointed out that assimilation may occur to different extents in the same substrate with different species of the genus *Spirillum*. Incubating *Pseudomonas calcoacetica* and *Escherichia coli* in the presence of different substrates, Clifton (4) noted that regardless of the initial concentration of substrate, or of organisms, and of the presence of end products of respiration in the suspension medium, the same general pattern of oxidative assimilation was observed. Clifton (5) observed that the oxidation of various substrates by *Pseudomonas calcoacetica* in a phosphate buffer tended to proceed to completion in the presence of appropriate concentrations of sodium azide, or 2,4-dinitrophenol, both of which are inhibitors of assimilation processes. He also studied the effects of different concentrations of these inhibitors. It appears that the processes of respiration and assimilation are closely related and influenced by the same agents. Clifton concluded that low concentrations of the inhibitors initially inhibit respiration slightly and simultaneously partially prevent synthesis. Critical concentrations of the inhibitory agent significantly prevent synthesis and force the reaction in the direction of complete oxidation to carbon dioxide and water, the rate of oxygen consumption being somewhat further reduced. Higher concentrations of the inhibitors reduce the rate of respiration to a negligible value.

Further observations of inhibition were made by Clifton and Logan (6) using *Escherichia coli* in demonstrating that sodium azide and 2,4-dinitrophenol in suitable concentrations tend to increase the oxidation of acetate, lactate, pyruvate, glycerol, fumarate, succinate, and glucose. From this investigation, it appears that the assimilatory reactions are functions of the chemical constitution of the substrate rather than of the free available energy of the substrate. Pickett and Clifton (7) obtained data which indicated that the effect of sodium azide and 2,4-dinitrophenol on the oxygen utilization in the presence of glucose varied not only between species of an organism but also within a given species. Therefore, these authors suggested that the inhibitory agents act on more than one enzyme, or enzyme system, and the inhibition of assimilation probably results from the blocking of a series of enzymatic reactions.

The effect of various concentrations of 2,4-dinitrophenol on the activity of activated sludge in relation to the operation of sewage treatment plants was studied briefly by Rich and Yates (8). Both stimulatory and inhibitory effects appear to be reversible in the oxidation of synthetic sewage. The stimulation increased with increasing 2,4-dinitrophenol concentrations during short periods of aeration, but for concentrations as low as 5 mg/l the 2,4-dinitrophenol tended to inhibit the activity as the aeration time increased. However, no inhibitory effect was observed for long periods of aeration when a 4 mg/l concentration of 2,4-dinitrophenol was employed.

BOD Progression

The cumulative daily oxygen utilization of microorganisms feeding on domestic sewage often conforms closely to the graphic plot of the first-order reaction equation. The validity of the first-order assumption in the stabilization of industrial wastewaters has not yet been established. Many workers in their analysis of the exponential BOD formulation for soluble organic

wastes have reported variations in the present five-day determination. While studying these variations in the biological oxidation of milk wastes in 1953, Hoover *et al.* (9) proposed a two-phase BOD progression. This theory postulated two biochemical reactions; i.e., that the oxygen utilization during the second phase is due to the endogenous respiration of the bacterial cell material produced by assimilation of the substrate during the first phase. In 1954, Buswell *et al.* (10) concluded that the monomolecular law is invalid for the BOD determination and agreed with the conclusions of Hoover.

More recently, Busch (1) presented a similar theory on the progression of the BOD of soluble substrates as a multi-stage reaction. According to this theory, the first stage represents the assimilation of available nutrients into cell material plus intermediate stored products. Subsequent utilization of oxygen in excess of endogenous respiration is attributed to the activity of protozoa and higher organisms feeding on the bacteria. Busch obtained a "plateau" value of oxygen utilization representing the consumption of all the substrate by the bacterial cells. This plateau in oxygen utilization yielded a characteristic value for a given substrate. For soluble organic substrates, Busch stated that the plateau value offers a more valid point for determining the total load or "ultimate" oxygen demand than does the conventional five-day incubation test.

From the above discussion, the need for a clear and definite delineation of the progression of the BOD in order that an accurate short-term determination may be established is evident. With the establishment of the validity of the first-stage plateau as a reproducible percentage of the theoretical BOD, this study was initiated to determine the possibility of increasing this percentage by selective poisoning of the bacterial assimilatory processes using the technique developed by Clifton (5). The result of blocking assimilation would be an increased respiration and thus a higher ratio of plateau values to theoretical BOD.

Experimental Methods

In this investigation, both manometric and bottle dilution techniques (11) (12) (13) were employed for the determination of BOD values. The manometric procedure requires the use of relatively high concentrations of both substrate and seeding organisms. Therefore, these experimental conditions are directly related to the concentration of substances normally found in wastewater treatment plants but are markedly higher than those encountered in pollution studies of streams. This procedure was used to study the broad aspects of the problem where it was not feasible to prepare large numbers of bottle samples. Bottle determinations were used to confirm the results of the manometric method in dilutions applicable to stream conditions. It is seen, therefore, that the techniques employed encompass the broad realm of biological oxidation, from waste treatment plant design to pollution control studies.

Experimental Results

Selective Stimulation of the Respiration of Glutamic Acid

The BOD values obtained with the manometric procedure for a heterogeneous population of microorganisms during 120 hr of incubation in the presence of a 300 mg/l solution of glutamic acid and various concentrations of sodium azide are plotted as a function of time in Figure 2, which presents a typical pattern of the inhibition of assimilation. As shown in Figure 2, after an initial lag period the BOD proceeds at a relatively constant rate and on reaching a value

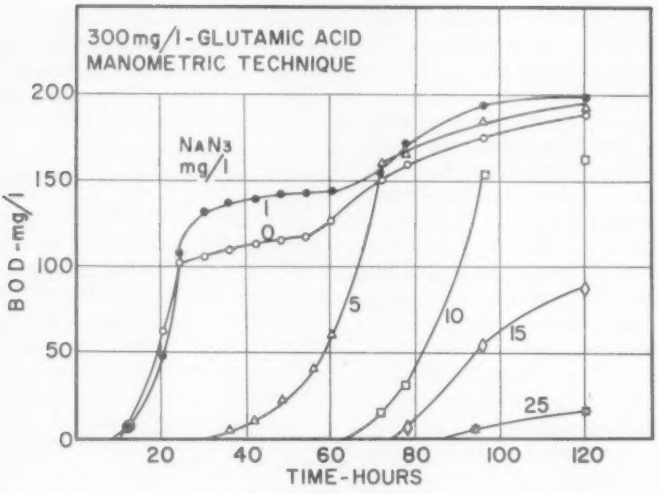


FIGURE 2.—Effect of sodium azide on BOD of 300-mg/l glutamic acid solution using manometric technique (0–25 mg/l NaN_3).

characteristic for a particular concentration of sodium azide, decreases to a rate near that of the control sample of the substrate. This change in rate of respiration, or plateau value, corresponds to the depletion of the substrate from the medium. However, for the glutamic acid sample containing 5 mg/l sodium azide, the plateau values were substantially higher than the control, indicating an increase in respiration due to the selective inhibi-

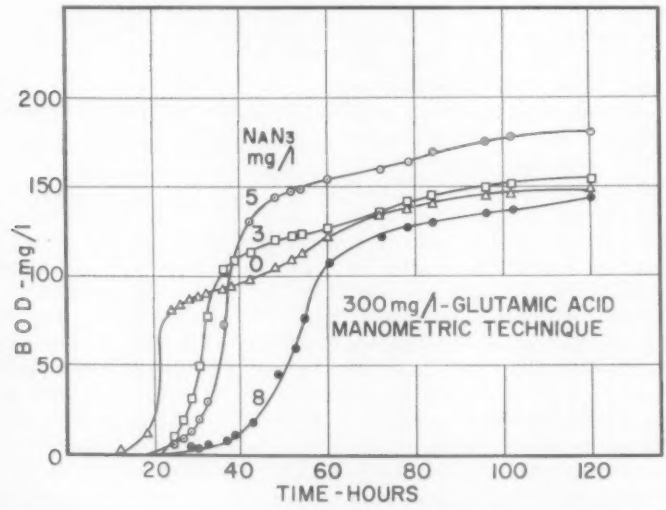


FIGURE 3.—Effect of sodium azide on BOD of 300-mg/l glutamic acid solution using manometric technique (0–8 mg/l NaN_3).

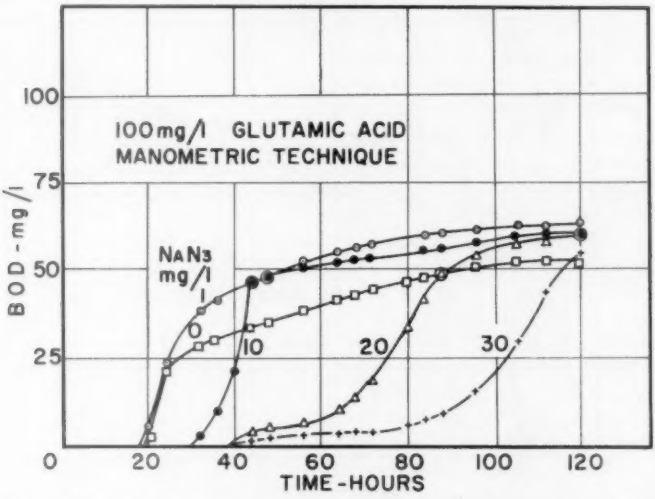


FIGURE 4.—Effect of sodium azide on BOD of 100-mg/l glutamic acid solution using manometric technique.

tion of the assimilatory processes. It is noted for glutamic acid that increasing concentrations of sodium azide produced a prolonged lag period and a decreased rate of oxidation. Figure 3 shows BOD values for a 300 mg/l glutamic acid solution containing 3, 5, and 8 mg/l sodium azide. It is especially important to observe the different mode of action of the 5- and 8-mg/l sodium azide samples. The 8-mg/l sample did not yield a plateau value equivalent to the control, thus indicating not only partial blocking of

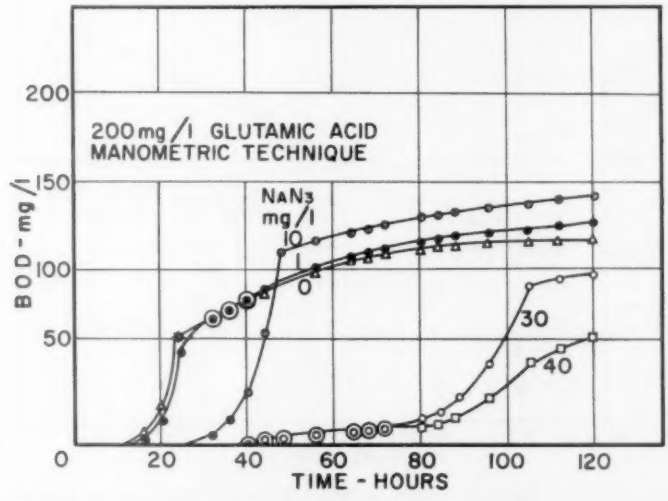


FIGURE 5.—Effect of sodium azide on BOD of 200-mg/l glutamic acid solution using manometric technique.

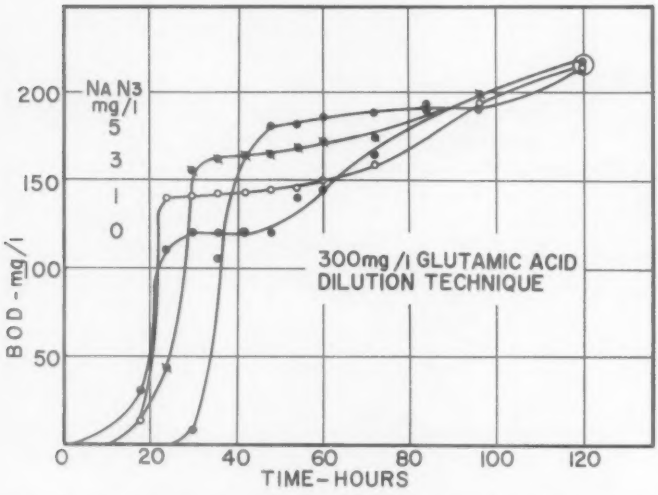


FIGURE 6.—Effect of sodium azide on BOD of 300-mg/l glutamic acid solution using dilution technique (0–5 mg/l NaN_3).

the assimilation process but also inhibition of respiration. This graph clearly denotes the existence of a critical concentration of the inhibitory agent which blocks assimilation and yet forces respiration toward completion. The same typical pattern of stimulation of respiration is observed for 100- and 200-mg/l glutamic acid samples presented in Figures 4 and 5, respectively.

Bottle dilution studies are reported

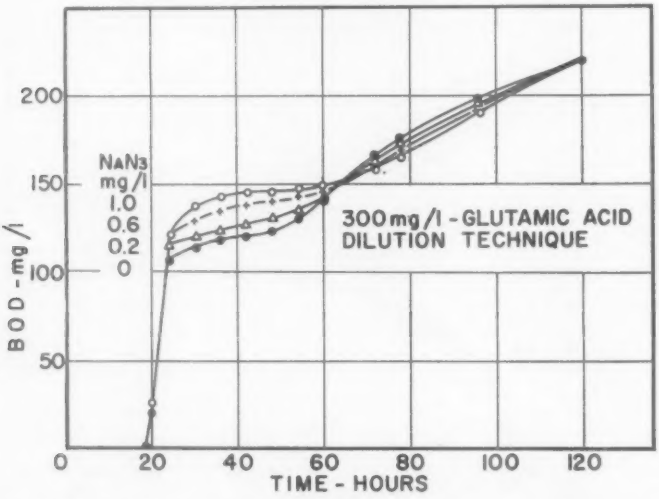


FIGURE 7.—Effect of sodium azide on BOD of 300-mg/l glutamic acid solution using dilution technique (0–1.0 mg/l NaN_3).

TABLE I.—Influence of 2,4-Dinitrophenol on BOD of 300-mg/l Glutamic Acid Solution by a Mixed Culture of Microorganisms (Manometric Method)

Hours Incubation	BOD in mg/l for Various Concentrations of 2,4-Dinitrophenol			
	0*	1*	5*	15*
0	0	0	0	0
12	4	4	4	3
18	17	14	14	12
20	33	30	30	27
24	78	75	76	79
28	90	89	88	92
36	100	99	98	102
38	112	110	110	113
42	116	114	113	116
46	117	115	115	117
48	120	117	117	119
56	127	125	125	126
60	131	128	128	130
66	136	132	133	135
72	139	136	136	140
84	147	142	144	148
108	156	149	156	157
120	157	150	158	158

* mg/l 2,4-dinitrophenol.

in Figures 6 and 7 for a 300-mg/l glutamic acid solution. It is noted that five-day values are practically identical and well within the accepted standard deviation (13). The plateau values are equally reproducible in the cases where they are duplicated. The sensitivity of the phenomena of selective stimulation of respiration is well demonstrated by the plateau values obtained in Figure 7. The two experiments reported in Figures 6 and 7 utilized seed collected at two different times from the same treatment plant.

The other inhibitory agents of assimilation studied in a solution of glutamic acid were sodium fluoride and 2,4-dinitrophenol. These agents showed no marked degree of either stimulation or inhibition within the inhibitor concentration ranges studied. Typical results of these manometric experiments are presented in Table I, for 2,4-dinitrophenol, and in Table II, for sodium fluoride. Similar results were obtained for 100-mg/l and 200-mg/l glutamic acid solutions in the presence

TABLE II.—Influence of Sodium Fluoride on BOD of 300-mg/l Glutamic Acid Solution by a Mixed Culture of Microorganisms (Manometric Method)

Hours Incubation	BOD in mg/l for Various Concentrations of Sodium Fluoride					
	0*	1*	5*	10*	15*	20*
0	0	0	0	0	0	0
10	3	3	4	5	4	4
18	19	18	20	20	19	20
20	42	41	43	40	42	45
26	77	77	79	74	78	67
28	82	81	84	79	83	85
34	91	88	93	88	92	93
40	96	95	98	93	97	98
48	107	105	108	103	107	106
52	115	112	114	109	114	112
58	124	121	124	118	124	124
78	138	136	139	133	138	144
96	147	145	149	141	147	153
120	150	149	152	145	151	158

* mg/l sodium fluoride.

TABLE III.—Influence of Sodium Azide on BOD of 300-mg/l Glucose Solution by a Mixed Culture of Microorganisms (Manometric Method)

Hours Incubation	BOD in mg/l for Various Concentrations of Sodium Azide			
	0*	1*	5*	10*
0	0	0	0	0
12	3	2	0	0
22	36	21	18	10
24	52	31	27	16
26	66	43	38	23
28	82	52	54	33
30	86	73	62	42
34	91	88	85	53
36	93	89	94	55
42	96	93	107	85
48	99	101	111	108
54	104	104	114	123
60	110	108	116	127
72	125	125	121	133
78	130	132	122	136
84	135	137	125	138
96	141	144	133	144
108	148	152	143	154
120	152	156	159	160

* mg/l sodium azide.

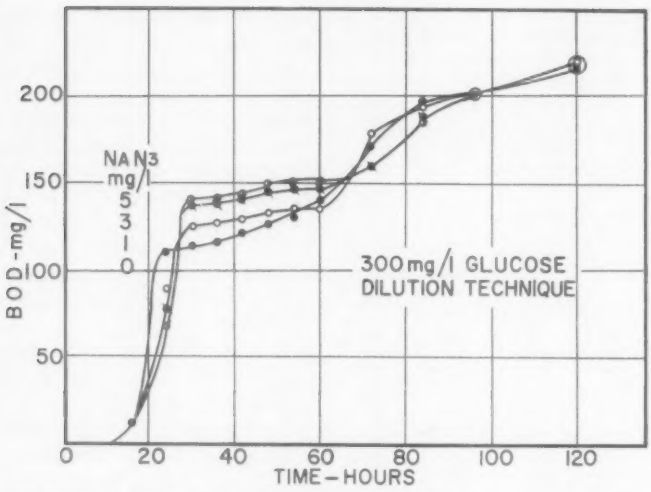


FIGURE 8.—Effect of sodium azide on BOD of 300-mg/l glucose solution using dilution technique.

of various concentrations of 2,4-dinitrophenol.

Selective Stimulation of the Respiration of Glucose

The same general pattern of stimulation of respiration noted with glutamic acid was exhibited in experiments employing glucose as the substrate and sodium azide as the in-

TABLE IV.—Influence of 2,4-Dinitrophenol on BOD of 300-mg/l Glucose Solution by a Mixed Culture of Microorganisms (Bottle Dilution Technique)

Hours Incubation	BOD in mg/l for Various Concentrations of 2,4-Dinitrophenol			
	0*	1*	3*	5*
0	0	0	0	0
12	0	0	0	0
18	26	34	41	30
24	107	105	101	99
30	112	112	112	114
36	118	118	122	118
42	120	120	122	122
48	122	126	124	124
54	135	136	135	135
60	161	154	172	165
72	187	187	193	195
84	202	202	199	206
96	221	214	217	215
120	221	217	217	217

* mg/l 2,4-dinitrophenol.

TABLE V.—Influence of Sodium Azide on BOD of 300-mg/l Solution of a 1:1 Mixture of Glucose and Glutamic Acid by a Mixed Culture of Microorganisms (Manometric Method)

Hours Incubation	BOD in mg/l for Various Concentrations of Sodium Azide			
	0*	1*	3*	5*
0	0	0	0	0
12	4	5	2	2
18	15	15	7	6
22	52	47	25	17
24	79	84	78	53
30	85	92	102	83
36	91	98	109	94
40	93	100	110	95
48	107	112	116	104
54	117	123	120	108
60	124	132	130	115
64	127	136	137	121
72	135	143	147	130
78	138	147	151	134
84	141	150	154	137
88	142	151	155	139
96	144	153	159	142
108	146	156	162	145
120	149	156	164	148

* mg/l sodium azide.

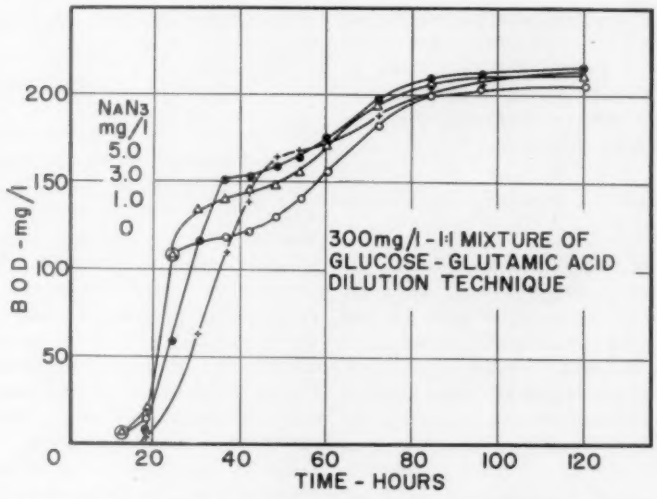


FIGURE 9.—Effect of sodium azide on BOD of 300-mg/l mixture of glucose and glutamic acid using dilution technique.

hibitor. Typical results from manometric studies are presented in Table III. This substrate was also studied in bottle dilution experiments. Typical data from one of these experiments are plotted in Figure 8. Table IV gives data on an experiment studying the effect of 2,4-dinitrophenol on glucose oxidation. From these bottle dilution studies, it is noted that 2,4-dinitrophenol had neither a stimulative nor inhibitory effect on the oxidation of glucose within the inhibitor concentration range employed.

TABLE VI.—Influence of Sodium Azide and 2,4-Dinitrophenol on BOD of Fresh Sewage (Manometric Method)

Hours Incubation	BOD in mg/l for Various Concentrations of Sodium Azide and 2,4-Dinitrophenol								
	0*	5*	10*	20*	30*	5†	10†	20†	30†
0	0	0	0	0	0	0	0	0	0
12	33	32	31	28	22	34	35	33	32
16	39	37	36	33	30	39	39	39	42
20	48	46	45	43	40	48	51	49	50
24	53	50	50	48	46	52	54	53	54
36	58	56	55	53	50	59	61	61	60
48	62	60	60	59	58	61	64	65	64
60	70	67	65	64	63	67	72	72	71
72	76	74	73	72	70	75	81	81	81
84	82	79	79	78	74	82	86	88	88
96	85	83	84	82	79	86	88	91	92
108	91	88	91	87	85	91	92	95	95
120	94	97	93	89	88	92	93	96	97

* mg/l sodium azide.
† mg/l 2,4-dinitrophenol.

Selective Stimulation of the Respiration of Glutamic Acid and Glucose

For studies using a 1:1 mixture of glutamic acid and glucose as the substrate, results similar to those found for glutamic acid and glucose alone were obtained when sodium azide was used as the inhibitory agent. Typical data for a manometric experiment are presented in Table V. Typical results obtained from a dilution experiment are plotted in Figure 9.

Selective Stimulation of the Respiration of Sewage

An experiment using fresh settled sewage in the presence of various concentrations of sodium azide and 2,4-dinitrophenol was performed. The

data from this experiment are found in Table VI. It is noted that there was no well defined degree of stimulation of respiration in these samples. The same sewage was used for the study of both inhibitors.

Net Stimulation Produced by Sodium Azide

The net stimulation produced by sodium azide using the bottle dilution technique is shown in Figure 10 for each substrate at a specific incubation time. It is noted that the stimulation effect is not linear and at higher sodium azide concentrations the inhibition of respiration becomes significant.

Stimulation of Respiration of Various Substrates Due to Sodium Azide

The extent of the increase in oxidation of the various substrates is presented in Table VII. The theoretical carbonaceous BOD is based on two equations. For glucose the equation is

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O \quad (1)$$

and for glutamic acid

$$C_5H_9O_4N + 4.5\ O_2 \rightarrow 5CO_2 + 3H_2O + NH_3 \ldots (2)$$

The per cent of the theoretical oxidation of glucose in the presence of 5 mg/l sodium azide was 46.7 as compared to 38 for the samples without sodium azide. The net increase in oxidation was 8.7 per cent. For glutamic acid and the mixture, the increase in the presence of 5 mg/l sodium azide was 23.7 and 16.6 per cent, respectively. It should be noted that the per cent increase was taken from the plateau on the respective curves and that in some cases the time differential is on the order of 18 hours because of the lag induced by the inhibitor.

Effect of Sodium Azide on Lag Period

The effect of sodium azide on the lag period is presented in Figure 11. For a given BOD value, the ratio of the time of the lag in the sample to that of the sample is plotted as a func-

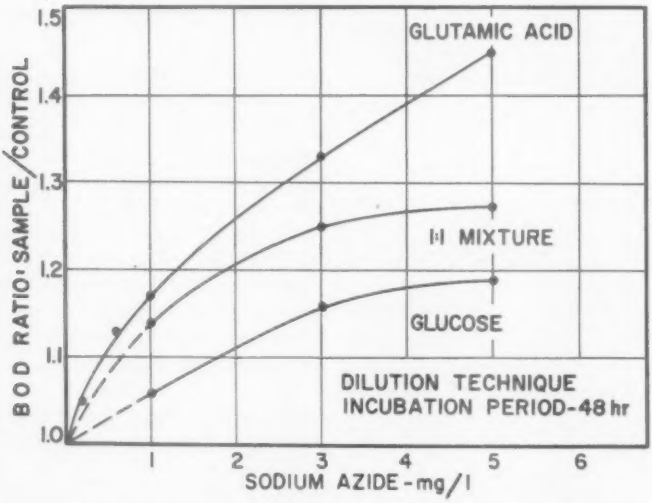


FIGURE 10.—Net stimulation produced by sodium azide using the bottle dilution technique.

TABLE VII.—Stimulation of Respiration of Various Substrates Due to Sodium Azide

Substrate (300 mg/l)	Sodium Azide (mg/l)	Hours Incubation	BOD (mg/l)	Theoretical BOD (mg/l)	Per Cent Theoret ca BOD
Glucose*	0.0	42	122	321	38.0
	1.0	48	133	321	41.4
	3.0	54	146	321	45.5
	5.0	54	150	321	46.7
Glutamic acid†	0.0	36	120	273	43.7
	0.2	36	124	273	45.4
	0.6	36	135	273	49.4
	1.0	36	140	273	51.3
	3.0	42	165	273	60.4
	5.0	54	184	273	67.4
1:1 mixture of glucose-glutamic acid‡	0.0	36	118	297	39.7
	1.0	42	146	297	49.2
	3.0	42	154	297	51.9
	5.0	54	167	297	56.3

* See Figure 8.
† See Figures 6 and 7.
‡ See Figure 9.

tion of the concentration of sodium azide. It is readily observed that the lag period in these bottle dilution experiments is of longer duration for higher concentrations of sodium azide. The effect of sodium azide is not linear. However, the effect exhibits a characteristic pattern for each substrate studied in this biological environment.

Discussion of Results

The results obtained from the experiments presented in the preceding

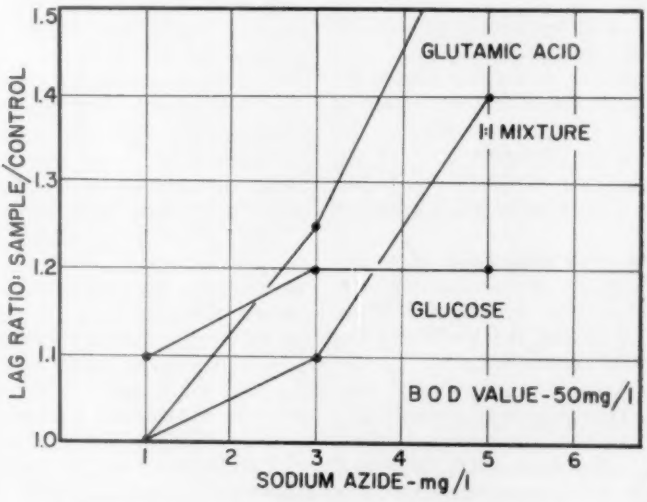


FIGURE 11.—Effect of sodium azide on the lag period.

discussion clearly demonstrate that it is possible selectively to stimulate respiration (oxidation) of glutamic acid, glucose, and a 1:1 mixture of these compounds by a mixed culture of microorganisms in the presence of sodium azide, an inhibitory agent of assimilation (synthesis). It was observed that a critical concentration of this inhibitory agent significantly prevented synthesis and forced the reaction in the direction of complete oxidation to carbon dioxide and water, the degree of which was indicated by a plateau value. Low concentrations of sodium azide initially retarded respiration slightly and simultaneously the synthesis processes were partially inhibited. Relatively high concentrations of this agent reduced the rate of respiration appreciably. This was the typical pattern observed for glutamic acid, glucose, and the mixture of these substrates studied in a solution of sodium azide. This pattern is similar to the one reported by Clifton and various other workers for the oxidation of high concentrations of substrates by heavy inoculums of pure cultures of microorganisms during short periods of incubation.

Other inhibitory agents of assimilation, such as 2,4-dinitrophenol and sodium fluoride, showed no marked degree of stimulation or inhibition of respiration of these substrates. No increase in the oxidation of fresh settled sewage was observed due to the action of sodium azide and 2,4-dinitrophenol.

The use of a population of microorganisms grown on the substrate to be studied should be investigated in an attempt to reduce the prolonged lag period of the control samples.

It was observed that the bottle dilution technique gave more reproducible results than the manometric method. As noted in Figures 2 and 3, the 5-mg/l curves for the manometric technique show different rates of oxidation and different lag periods. Similar variations existed in all cases where the manometric experiments were duplicated. These variations in the manometric experiments are probably due to the larger number of microorganisms present in this biological environment as compared to that found in the BOD bottle. In addition, different five-day BOD values were obtained with the two techniques.

The plateau phase obtained in the curves for the various substrates in the presence of sodium azide with both techniques is in agreement with the multistage BOD reaction as postulated by Busch (1). It is important to note that the rate and path of oxidation can be altered noticeably and yet still attain five-day BOD values which are within the accepted standard deviations for these substrates with the dilution technique.

Summary

An investigation was made of the selective stimulation of respiration in mixed cultures of bacteria. The study utilized both manometric and dilution techniques in BOD measurements. The objectives of this work were twofold: (*a*) the further delineation of the progression of the BOD in soluble substrates as a multistage reaction; and (*b*) the determination of whether the percentage of oxidation represented by the plateau values of the BOD curve could significantly be increased by selectively blocking assimilation.

That the theory proposed by Busch in 1958 is correct was clearly demonstrated by the increase in plateau values in the presence of inhibitors of assimilation. Although substantial increases in plateau values were obtained for glucose, glutamic acid, and a 1:1 mixture of these, in combination with sodium azide, the lag induced by partial inhibition of respiration offsets any particular advantage of its use in a short-term BOD test. Other inhibitory

agents studied showed no significant effects.

Conclusions

The following conclusions may be drawn:

1. The progression in soluble substrates of BOD exerted by mixed cultures of sewage organisms seed is a multistage reaction. A plateau occurs in the oxygen consumption curve on completion of direct substrate oxidation. The rate and the path of the progression can be altered appreciably by the use of an approximate inhibitor of assimilation (synthesis) processes and yet produce five-day BOD values which are within the accepted standard deviations for these substrates with the dilution technique.

2. It is possible selectively to stimulate the respiration (oxidation) of glutamic acid, glucose, and a 1:1 mixture of these compounds by a mixed culture of microorganisms with sodium azide.

3. A critical concentration of sodium azide significantly prevents synthesis and forces the reaction in the direction of complete oxidation to carbon dioxide and water as shown by increased plateau values. Low concentrations (on the order of 1 to 2 mg/l) of sodium azide initially retard respiration slightly and simultaneously the synthesis processes are partially inhibited. Relatively high concentrations (greater than 5 mg/l) of this agent reduce the rate of respiration substantially.

4. The critical concentration of sodium azide is 5 mg/l in bottle dilution studies for 300-mg/l solutions of glutamic acid, glucose, and a 1:1 mixture of these compounds. This concentration was in the same order of magnitude for the manometric studies.

5. Over-all patterns of stimulation are similar to those reported by other workers using pure cultures of microorganisms.

6. Two other inhibitory agents of assimilation, 2,4-dinitrophenol and sodium fluoride, show no marked degree of stimulation or inhibition of oxidation of these substrates.

7. Neither sodium azide nor 2,4-dinitrophenol increased the oxidation of fresh settled sewage.

Acknowledgment

This study was supported in part by N.I.H. Grant RG 5534.

References

1. Busch, A. W., "B.O.D. Progression in Soluble Substrates." *Sewage and Industrial Wastes*, **30**, 11, 1336 (Nov. 1958).
2. Barker, H. A., "The Oxidative Metabolism of the Colorless Alga, *Prototheca zopfii*." *Jour. Cellular and Comparative Physiol.*, **8**, 231 (1936).
3. Giesberger, G., "Beitrage zur Kenntnis der Gattung Spirillum Ehbg." Dissertation, Univ. of Utrecht, Netherlands (1936).
4. Clifton, C. E., "On the Possibility of Preventing Assimilation in Respiring Cells." *Enzymologia*, **4**, 246 (1937).
5. Clifton, C. E., "Oxidative Assimilation by Micro-organisms." In "Enzymes," Vol. 2, p. 912, Academic Press Inc., New York (1952).
6. Clifton, C. E., and Logan, W. A., "On the Relation Between Assimilation and Respiration in Suspensions and in Cultures of *Escherichia coli*." *Jour. Bact.*, **37**, 523 (1939).
7. Pickett, M. J., and Clifton, C. E., "The Effect of Selective Poisons on the Utilization of Glucose and Intermediate Compounds by Micro-organisms." *Jour. Cellular and Comparative Physiol.*, **22**, 147 (1943).
8. Rich, G. L., and Yates, O. W., "The Effect of 2,4-Dinitrophenol on Activated Sludge." *Applied Microbiol.*, **3**, 2, 95 (1955).
9. Hoover, S. R., Jasewicz, L., and Porges, N., "An Interpretation of the B.O.D. Test in Terms of Endogenous Respiration of Bacteria." *Sewage and Industrial Wastes*, **25**, 10, 1163 (Oct. 1953).

10. Buswell, A. M., Mueller, H. F., and Van Meter, I., "Bacteriological Explanation of Rate of Oxygen Consumption in the B.O.D. Test." *Sewage and Industrial Wastes*, **26**, 3, 276 (Mar. 1954).
11. Caldwell, D. H., and Langelier, W. F., "Manometric Measurement of the B.O.D. of Sewage." *Sewage Works Jour.*, **20**, 2, 202 (Mar. 1948).
12. Ludwig, H. E., Oswald, W. J., and Gotaas, H. B., "Manometric Technique for Measurement of B.O.D." Institute of Engineering Research, Univ. Calif., Berkeley (1951).
13. "Standard Methods for the Examination of Water, Sewage, and Industrial Wastes." 10th Ed., Amer. Pub. Health Assn., New York (1955).

QUARTER CENTURY OPERATORS' CLUB

Have you been an operator for 25 years? If so, you may be eligible for membership in the Quarter Century Operators' Club.

This Club is an informal group comprising Active or Corporate Members of any Member Association who had been engaged in treatment works operation, on a full-time resident basis, 25 years prior to the date of their admission into the Club. A candidate need not now be engaged in treatment plant operation, but he should have a continuing interest.

If you are interested in joining this select group you may obtain information and application forms from: Mr. Henry Van Der Vliet, P. O. Box 281, Rutherford, N. J.

INDUSTRY FUTURE WATER REQUIREMENTS

Future water requirements for the major industries is the subject of a committee report to the Senate Select Committee on National Water Resources. This 100-page report contains a wealth of tabulated data, discussing water use requirements geographically and by specific industry. The major industries are classed as iron and steel, chemicals and allied products, pulp and paper, food and beverage, aluminum, copper, and minerals.

The title of the report is "Water Resources Activities in the United States, Future Water Requirements of Principal Water-Using Industries." It is Committee Print No. 8, 86th Congress, 2nd Session, printed for the use of the Select Committee on National Water Resources, dated April 1960.

Single copies may be obtained from:

Mr. Walter L. Picton
Director, Water and Sewerage Industry and Utilities Division
Business and Defense Services Administration
Department of Commerce
Washington 25, D. C.

POLLUTION ABATEMENT IN THE SUGAR INDUSTRY OF LOUISIANA *

By Arthur G. Keller and H. K. Huckabay

Professor of Chemical Engineering and Graduate Assistant, Louisiana State University, Baton Rouge, La.

It is the purpose of this paper to discuss briefly the background, method of approach, and success achieved in the abatement of pollution in the Louisiana cane sugar industry. The background will consist of a brief description of cane sugar processing and of the various geographical, social, and economic factors which have contributed to the problem (1) (2). The action by state agencies and the industry will be covered under the method of approach, while the solutions to the problem will be discussed finally (1) (3).

Sugar cane is, in the strictest sense, a giant grass. The cane, which contains the sugar bearing juices, grows 10 to 20 ft high and 1 to 3 in. in diameter. Sugar cane is cultivated throughout the world in a belt extending from 30 deg S Lat to 30 deg N Lat. Some 56 countries participate with a total yearly production of 27 mil metric tons. Three-quarters of the contribution of the United States to this total is grown and processed in 20 parishes (counties) of south central Louisiana (Figure 1).

The cane in this climate matures once a year with harvesting and initial processing taking place from October to January. It can be seen that this pollution problem tends to be concentrated both in location and time.

These 20 parishes which form the production and processing area of Louisiana are flat delta land, traversed by numerous sluggish rivers and bayous. These streams drain large swamp areas and, as a result, tend to carry a high pollution load in their natural state. In late summer and early fall, flow rate tends to be very low. In many cases these streams become septic in their natural condition.

In addition, following a series of disastrous floods in 1927, extensive flood control work has taken place in this area. The result has been to make many streams, such as the Teche, flow in the direction the wind is blowing or the tide is running. This makes the pollution stabilization capacity of the stream even more difficult to predict and use efficiently.

Moreover, the pollution potential of the cane sugar industry is very large. To understand this, one must know something of the process.

Cane Sugar Processing

The process begins with the harvesting of the cane. This consists of severing the cane at the ground and trimming off the top and any adhering leaves. Formerly, harvesting was done manually, with the machete or cane knife. This procedure is still used in such areas as Cuba. High labor costs, however, have brought an end to this practice in the United States, and harvesting is done mechanically (Figure 2). The mechanical cane harvester consists of upper and lower revolving knives and intermediate pointed rods to hold the cane while it is being cut. The mechanical method, although cheaper, results in more damage to the

* Presented at the 32nd Annual Meeting, Federation of Sewage and Industrial Wastes Assns.; Dallas, Tex.; Oct. 12–15, 1959.

FIGURE 1.—Sugar cane growing and processing areas of Louisiana.

cane as well as pickup of soil, trash, and other foreign material. The harvested cane generally runs 15 per cent by weight of fibrous material with the remainder water and dissolved solids. Under ideal conditions, 10 to 15 per cent of the original weight of the cane can be recovered as marketable sugar. Under less ideal conditions, this same amount can become water pollution.

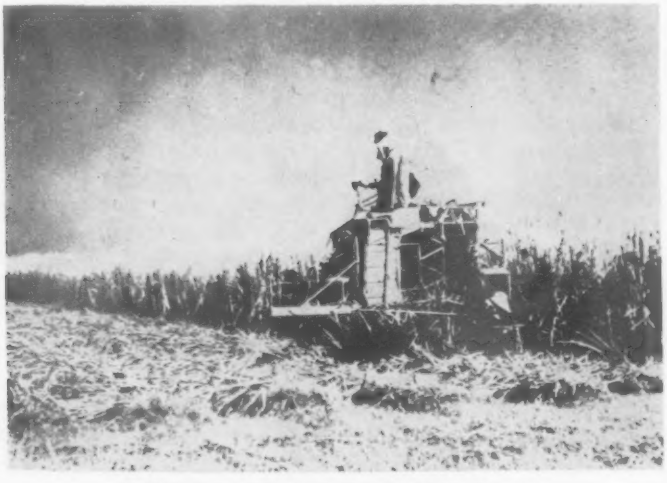


FIGURE 2.—Mechanical harvesting of sugar.

The difference lies in the efficiency and technology of operation. The basic operation consists of chopping the cane into short lengths and crushing it in a series of rollers. The juices extracted are collected below; the crushed fiber, with a residual sugar content, is termed "bagasse" and finds use as a low grade fuel, livestock feed, and raw material for paper pulp.

The juices are mixed with a slurry of calcium hydroxide to raise the pH to approximately 8.0, and then heated to 215°F. The heated juice is passed to a continuous sedimentation unit in which clarification is achieved. The bottoms, or "muds" are sent to a rotary vacuum filter; the filter cake consists chiefly of fibrous material and topsoil, with an average sugar content of 4 per cent by weight. The filtrate is recycled to the sedimentation unit. The clear liquid from the sedimentation unit is essentially a neutral solution of sucrose, and is sent to multiple-effect evaporators where the solution is concentrated from 16 per cent to 65 per cent solids. The final solution is evaporated under vacuum to crystallize the sucrose. The resulting crystalline product is the commercial "brown" sugar, and the spent liquor is termed molasses.

This is the basic process of cane sugar refining for clean cane. For cane harvested by the mechanical method, an initial washing must be added. If this is not done, the crushing rollers will slip and bind or may be damaged by foreign materials; also this initial washing keeps down the volume of filter cake, which, as was previously mentioned, contains about 4 per cent sugar by weight. When harvested from muddy fields, washing of cane is an absolute necessity for operation. The water can be reused only for a limited period, less than one hour, for organisms grow in this water which are capable of hydrolyzing the sucrose. While sucrose can be crystallized readily, its hydrolysis products cannot, so this would lead to another inefficiency.

Ten-Year State Study

For many years, the resultant magnitude of the pollution from cane processing was only a matter of surmise. Increasing populations and new industries with their resulting competition for water brought the problem into focus. The state control agency, the Louisiana Stream Control Commission, began, in 1944, a ten-year study of the problem with stream sampling and in-plant studies at the Audubon Sugar Factory of Louisiana State University. The result was that in 1954 the sugar industry was cited as the chief source of water pollution in the state. A number of mills were served with injunctions and others were threatened.

To a seasonal industry of marginal profits, these injunctions could mean financial ruin. The cane decomposes rapidly after being cut or reaching maturity in the field. Sugar cane constitutes the sole agricultural crop of commercial value in most of the parishes where it is grown, and furnishes the basis of income for most of those gainfully employed.

Industry Study

To study the problem more effectively and provide mutual assistance, a group of eight sugar mills formed the Louisiana Sugar Producers Waste Control Council. These mills entered into a cooperative project with the Department of Chemical Engineering at Louisiana State University. The project was both extensive and intensive. The biochemical oxygen demand, oxygen consumed from permanganate, and dissolved sugar in each effluent source in each mill were determined. BOD's and OC's were run weekly by L.S.U. personnel while OC's and alpha-naphthol sugar tests were run several times daily by the plants. Under a consent

TABLE I.—Typical Volume and Character of Waste*

Waste	Flow (gpm)	5-day BOD (mg/l)	Total Daily BOD	
			(lb)	(lb/ton capacity)
Cane wash water	1,000	680	8,157	3.4
Floor sweepings and blowdown	100	378	453	0.2
Acid and caustic	10	—	—	—
Condenser water	5,000	69	4,138	1.7
Total	6,110	—	12,748	5.3

* Daily capacity, 2,400 tons.

agreement with the Louisiana Stream Control Commission, the mills remained open while a large amount of data were collected and analyzed.

In comparison with the data of the Stream Control Commission there was essential agreement, but the latter tended to be conservative. In other words, the problem was worse than imagined.

Waste Reduction Measures

The sources of pollution (Table I) were isolated as condenser cooling water from the evaporators, cane wash water, sodium hydroxide and hydrochloric acid used in the cleaning of heat exchangers, filter cake, and floor sweepings (2). The process was broken down in terms of these sources and each examined with a view to choosing

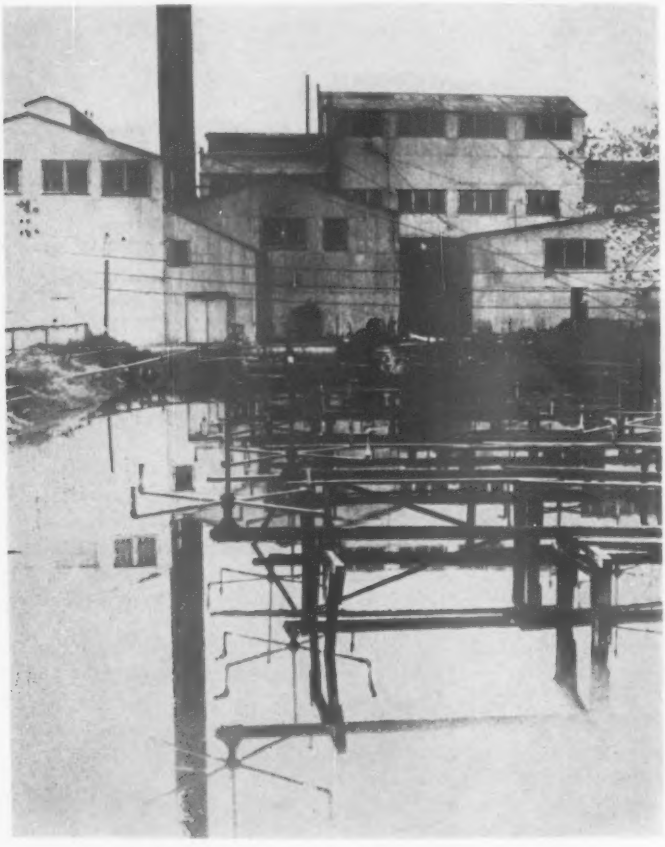


FIGURE 3.—Spray pond for aeration of wastes.

FIGURE 4.—Lagoon for further waste stabilization.

the most economical method of elimination.

The sugar loss in the condenser cooling water from the evaporators was found to be due to entrainment of liquid in the vapors. By installation of more efficient entrainment separators, the BOD was reduced, in two cases, from several thousand to 20 or 30 mg/l. The savings, in each of these two cases, amounted to around $2,500 per day.

The sodium hydroxide and hydrochloric acid used as cleaning agents were small in volume, and by impounding together a partial neutralization was achieved. This product then was bled off slowly into a large volume of discharge, such as condenser water, with no complaints.

The floor sweepings were the result of leaking pipes and improper and careless operation. As in the case of the condenser water, when the magnitude of the problem was demonstrated in terms of product that was not going to market, the improvements were rapid and complete.

It had been customary to pump the filter cake into the nearest stream as a slurry. In this fashion, it was not only a source of pollution but also a loss of valuable topsoil and fertilizer. By the simple expedient of returning

this to the fields as fertilizer both the stream and the fields benefited at small cost.

There remained, then, only the problem of the cane wash water. By counter-current washing, its volume could be reduced by almost any amount. In any case, this effluent does not lend itself to economical recovery of any product and was not found to settle to any extent. Various techniques of flocculation were attempted, as well as chemical oxidation, without any economic success in either case (3).

The answer was found to be lagooning and stabilization by organisms. Laboratory-scale reactor studies were undertaken to determine the effects of temperature and of nutrient addition on reaction rates. From these data, the lagooning system was designed as a multibasin system, the first basin being aerated (Figure 3) and with sufficient capacity for two days' effluent. These basins characterize themselves by decreasing the BOD from 1,000 to several hundred, the reduction resulting from the contact of fresh wastes with established populations of organisms. The effluent passes successively through two or more lagoons (Figure 4) and ends up, under proper operating conditions, with a BOD suitable for discharge (3).

In some cases, where the factory is located conveniently to large rivers such as the Mississippi, the wastes may be discharged directly. Alternately, the effluent has been disposed of by pumping to adjacent swampland owned by the mill. No decrease in value of the land as wildlife habitat has been observed.

But these are extreme cases. The basic technique must be refined so that factories located in an area where land is at a premium can wash cane sufficiently for proper operation and be able to stabilize wastes rapidly and without odor complaints.

Conclusions

The situation has improved steadily. During the last season, no mills were cited for pollution. Research continues at L.S.U., directed now at refinement of lagooning techniques and cheap, efficient aeration.

Future problems will likely arise. As of present, the aerial application of some types of insecticides for control of the sugar cane borer may be shaping up into such a problem. But the writers are confident that these problems, as the previous ones, will be resolved to the satisfaction of all concerned.

References

1. Keller, A. G., "An Industrial Wastes Guide to the Cane Sugar Industry." Engineering Report, Department of Chemical Engineering, La. State Univ., Baton Rouge, La. (1958).
2. Wheeler, J. E., and Keller, A. G., "Water Pollution and the Sugar Industry," *Sugar Jour.*, **18**, 20 (1956).
3. Wheeler, J. E., "An Engineering Study of the Effluent Disposal Problems of the Louisiana Raw Sugar Industry." Dissertation, La. State Univ., Baton Rouge, La. (Aug. 1959).

33rd ANNUAL MEETING
WATER POLLUTION CONTROL FEDERATION

Philadelphia, Pa.
Sheraton Hotel

October 2–6, 1960
Convention Hall

Stream Pollution

WATER QUALITY CONTROL CONSIDERATIONS IN THE RED RIVER COMPACT *

I. INTRODUCTION

By Henry C. Beckman

U. S. Geological Survey, Rolla, Mo.; Chairman, Red River Compact Commission

The Red River Basin includes substantial areas in the States of Arkansas, Louisiana, Oklahoma, Texas, and a small tract in New Mexico. The total drainage area is about 95,000 square miles. The area differs widely in topography, geology, soils, and climate, as well as in agricultural and industrial development. Of special interest to this group is the fact that the average annual precipitation ranges from about 17 in. near the headwaters of the river in western Texas to 64 in. near its mouth in eastern Louisiana. This fact indicates that there is insufficient water to supply all present and foreseeable domestic, agricultural, and industrial needs in Texas and Oklahoma, the upper part of the basin. Occasionally there is too much water in Arkansas and Louisiana, the lower part of the basin, which results in serious flooding; however, some future water shortages there can also be foreseen.

The quality of the water in the surface streams of this basin is of great concern, as it ranges from good for practically all purposes in parts of the basin to unsuitable for many important uses in other parts. The principal contaminants of the water are contained in oil field brines which flow into the streams in some areas and the leaching of natural soluble salts from the soils and rocks in other areas. The details of these conditions and the steps that are being taken to remedy them will be described by those who follow on this panel.

Recognizing the present and future water requirements in the several parts of the basin and the problems connected therewith, and desiring to forestall costly and time-consuming controversies and lawsuits, the States of Arkansas, Louisiana, Oklahoma, and Texas, along with the Federal Government began negotiations in 1956, with the consent of Congress, to enter into an interstate compact for equitably apportioning the waters of the Red River and its tributaries among the four States. The negotiations were soon broadened to include water quality considerations.

Commission Make-up

The negotiating body, under the name of the Red River Compact Commission, consists of one representative from each State and one from the Federal Government. The Federal representative now serves as chairman of the group, without vote. Much of the underlying work of the Commission is performed by committees. A Legal Advisory Committee makes studies of the legal and administrative features

* Presented at the 32nd Annual Meeting, Federation of Sewage and Industrial Wastes Assns.; Dallas, Tex., Oct. 12–15, 1959.

of the contemplated compact and serves as legal advisor to the Commission. An Engineering Advisory Committee compiles and analyzes basic data on the quantity and quality of the available water supplies in the basin and the present and probable future water needs. This committee also serves as engineering advisor to the Commission, especially in regard to making water apportionments among the four States. An Engineering Subcommittee on Stream Pollution Control informs the Commission as to the location and extent of stream pollution and water quality degradation in the basin and advises on the manner and extent to which means for control should be included in the compact. These committees are performing their assigned functions effectively, which is a great help to the Commission.

Commission Activities

The phase of the Commission's activities of particular interest to this group relates to the control of interstate stream pollution. The question naturally arises as to what part, if any, the body that is to be set up to administer the compact could appropriately take, or should take, in dealing with this problem.

The members of the Commission feel that the primary responsibility for preventing stream pollution rests with the states themselves. Each of them now has an active program for accomplishing this purpose within its own borders. The Commissioners are aware of the means for correcting interstate stream pollution available through the services of the U. S. Public Health Service under U. S. Public Law 660. The Commission feels, however, that there is still a need for the compact administrative body to take a part in the field of pollution control. They definitely believe that the compact administrators should have the authority to make investigations regarding interstate stream pollution and recommend remedial actions by the state enforcement agencies or under the provisions of U. S. Public Law 660.

Whether the administrators should have the authority to issue abatement orders against stream polluters and enter into the courts to enforce such orders is a more serious and debatable question. Opinions vary somewhat between individual members of the Commission and its committees. The Commission is cognizant of the fact that a state agency, in trying to correct pollution on a stream within its borders, might be handicapped in its efforts through local opposition or interference, especially if the only serious damage caused by the pollution is in a downstream state. The Commission also feels that recourse under Public Law 660, involving the Public Health Service, might be slow; and that there is no guarantee that Public Law 660 will always operate effectively.

For these reasons the Commission is now considering another medium for giving relief to a state that is being injured by pollution in an upstream state if the other measures fail. To accomplish this, the compact might be written to authorize the Attorney General of the downstream state to bring suit in any state or federal district court having jurisdiction in the offending state against any individual, corporation, or governmental unit that is contributing to such pollution. No decision has yet been reached on this subject; it is being given further study.

This is as far as the Commission has gone in determining what provisions should be included in the compact for assisting in the control of interstate stream pollution.

On this panel are five authorities in the field of stream pollution control. Each is either in direct charge of pollution control measures in his state or has important responsibilities in this field. Each will cover one phase of the stream pollution problem in the Red River Basin.

II. QUALITY DEGRADATION OF THE RED RIVER BY NATURAL SOURCES

By H. M. Crane

Senior Sanitary Engineer, Oklahoma State Department of Health, Oklahoma City, Okla.

The population of the United States has now exceeded 177 million and by 1980 will be 275 million. By the year 2000, present population will have doubled to 350 million persons.

Present use of water amounts to about 240 bil gpd. If population and water use trends continue, in only 20 years from now that figure will be nearly 600 bil gpd.

There are millions of acre-feet of Red River water flowing virtually unused each year through hundreds of miles of water-hungry, fertile, agricultural lands and cities in the Red River valley.

One of the major reasons for its lack of utilization is the quality of water found in the river. The great drouth of 1952–57 clearly demonstrated that when water is needed most, its quality is at its worst.

If there are those who doubt the importance of water quality and question the impact of poor quality water on the community, they have only to read the newspapers in such cities as Dallas, Oklahoma City, or Wichita, when the quality of the municipal water supply deteriorated, either chemically or physically.

The Arkansas-Red River water quality conservation project, from which most of these data were taken, was initiated by the Public Health Service to determine factors which cause quality degradation of the waters of the Arkansas and Red Rivers, to identify the location and amount of waters of varying quality suitable for beneficial use, and to develop methods or measures for improvement of the over-all water quality. The project was started in July 1957 under authority of the Federal Water Pollution Control Act, to carry out the recommendations of the Arkansas-White-Red Basins Inter-Agency Committee Report of June 1957.

Chloride Problems

The major inorganic pollutants of the Red River waters are chlorides, sulfates, and silt, with chlorides being the most serious of these. The organic pollution, with a few exceptions, is under good control. Figure 1 shows the Red River Basin.

Unfortunately, there is no gadget today that economically will make a high quality water from a highly saline source. The solution to the ever-increasing demands for high quality water will not be the removal of salt from rivers—unless an unlimited source of cheap power is found—it will be the prevention of its entrance into the rivers in the first place. An example of this problem is the fact that more than one million acre-feet of water with a chloride concentration in excess of 250 mg/l flows past Gainesville, Texas, each year (1).

River Loadings

Table I (adjusted for records of the Red River just below Denison Dam) summarizes average discharge, chloride loadings, and weighted average chloride concentration at four strategic locations in the basin.

A comparison of the chloride concentration shows the influence of the high quality water entering the Red River from Blue River, Clear Boggy and Muddy Boggy Creeks, Kiamichi River, Little River, Rolling Fork, Cossatot, and other rivers and creeks of excellent quality below Denison.

A similar comparison of the chloride loadings shows that over 90 per cent

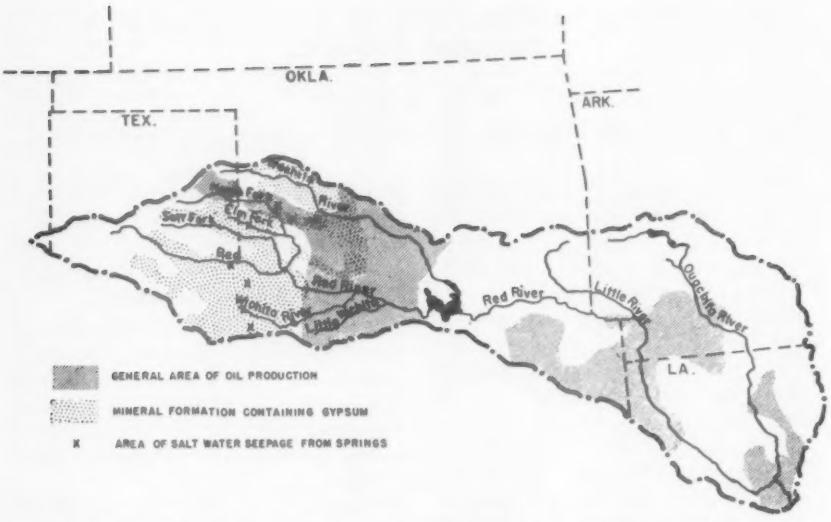


FIGURE 1.—Red River Basin showing sources of chlorides and sulfates.

of these chlorides are present in the river at Gainesville. This shows the major areas of mineral pollution to be in the upper reaches of the Red River.

The Wichita River basin is a classic example from the standpoint of mineral pollution (2). In the upper reaches of some of the tributaries, water of excellent quality is found, although usually in limited quantity. Beaver Creek above Lake Santa Rosa is an example of such water. Below the lake the quality deteriorates greatly prior to its confluence with the Wichita River. Other tributaries, such as the North Fork of the Wichita near Paducah, Texas, and the South Fork of the Wichita near Guthrie, Texas, originate as springs of fair quality, suitable for irrigation and other uses. As the North Fork and its tributaries flow eastward through areas of salt springs and salt water seepage, located about five miles southeast of Paducah, their chloride content increases sharply and remains far above acceptable standards as it reaches Lake Kemp.

TABLE I.—Comparison of All Stations Based on 1945–57 Period by Record at Denison Station

Station	Average Discharge (cfs)	Average Tons/Day (Cl^-)	Weighted Average (mg/l Cl^-)
Red River near Gainesville, Tex.	3,140	3,480	410
Washita River near Durwood, Okla.	1,710	176	38
Red River near Denison, Tex.	5,290	3,650	255
Red River near Shreveport, La.	23,300	3,760	60

Salt Springs

This salt spring area on the North Fork contributes 150 tons per day as chlorides, or 4.3 per cent of the total chloride loadings at Gainesville. Similar salt springs, contributing 150 tons per day, feed the South Fork in a six-mile stretch beginning approximately two miles east of Guthrie. Another salt spring area on the Middle Fork of the Wichita contributes 50 tons per day, or 1.4 per cent of the loadings at Gainesville. Below Lake Kemp and Lake Diversion, the Wichita River picks up additional chloride loadings from areas of oil production. Practically all mineral pollution in Lake Kemp, however, is from natural sources.

Two salt seepage areas on the Middle Pease River and North Pease River northwest of Paducah each contribute 40 tons per day of chlorides, or 1.1 per cent of the loadings at Gainesville.

Another major chloride contributing area is on the Elm Fork in northwest Harmon County, Oklahoma. Three small box canyons produce saturated or near saturated chloride solutions with flows totaling approximately 250 gpm. This amounts to 300 tons per day of chlorides, or 8.6 per cent of the loadings at Gainesville. Old records indicate that similar conditions existed in this area almost 50 years ago. A small salt plant at this location produces up to 10 tons per day of relatively high quality sodium chloride which is sold locally for water softeners and stock salt.

Estelline Springs, located on the banks of the Prairie Dog Town Fork of the Red River at Estelline, Texas, contributes 320 tons per day of chlorides, or 9.2 per cent of the loadings at Gainesville. This spring flows up through a gypsum formation, forming a typical sinkhole in the flood plain of the river. Flowing approximately 1,800 gpm of warm water, with a chloride content greater than sea water, the spring serves very well as the village swimming pool.

The areas mentioned above account for 1,050 tons of chlorides per day, or 30 per cent of the total loadings at Gainesville.

Proposed Solutions

There are at least five general categories which could be considered as possible solutions to the problem of controlling chlorides from this area.

1. Control of spring flows through compensating hydrostatic pressures. This could call for small channel dams to prevent seepage up through the river bottom or it might require flooding an entire area to prevent new outbreaks of salt springs. Most springs are located on the flood plains of major rivers or their tributaries and could be flooded by dam construction on the stream. It is interesting to note that in some areas salt collects on the surface of a flood plain, not by a normal spring flow but by capillary action of ground water up through the sand. Flooding such an area would stop the capillary action.

2. Injection into brine aquifers. If a compatible aquifer of sufficient size to handle large quantities could be located in areas of brine production or salt flows, this would be a permanent answer.

3. Storage and evaporation of salt water. This would withhold salt from the river for a time and may be a temporary solution but ultimately the salt would have to be controlled on a more permanent basis.

4. Diversion of stream flows around salt flat areas, isolating the area to as great an extent as possible. This is also a temporary solution if springs feeding the salt flats are not brought under control.

5. Piping of concentrated brines to the Gulf of Mexico. This may sound fantastic, but it could ultimately be the solution. The natural salt problem area runs in nearly a straight line from the Arkansas River in Kansas to the Colorado River in Texas. One line could serve all areas and would permanently dispose of the salt. Some of the previously mentioned temporary solutions could be a part of such a plan for the future.

Sulfates

The above possibilities will not solve the gypsum problem. During the last 12 years of record, a daily average of 189 mg/l of sulfates have been found in the Red River at Denison (2). Nearly all chloride springs are saturated with sulfates and controlling the flow would reduce the sulfates to some extent, but their main source is the extensive gypsum deposits and out-

crops exposed to surface waters throughout the basin (Figure 1). The ultimate solution, indicated by present limited data, is a leveling off of sulfate concentrations through storage and dilution to approach an acceptable average. Such a procedure would also reduce the maximum chloride concentrations now found during low flows.

Summary

At this time three interstate compacts involving the Arkansas and Red River Basins and five states are under negotiation. Each of the compact groups has concluded that water quality must be considered in relation to quantity. Each state is seeking new industry as well as working to improve its agriculture. The population loss experienced by the Red River Basin from 1940 to 1950 can be reversed when high quality surface waters are available throughout the basin for needed industrial and agricultural expansion.

References

1. "A Progress Report—Arkansas-Red River Basins Water Quality Conservation Project." U. S. Dept. Health, Education, and Welfare, Public Health Service, Region VII (June 1958).
2. Warkentin, E. C., "Improving Water Quality in the Red River." Presented at the Red River Valley Assn. Meeting, Shreveport, La. March 1959.

III. QUALITY DEGRADATION OF THE RED RIVER BY MAN-MADE SOURCES

By D. F. Smallhorst

Director, Division of Water Pollution Control, State Department of Health, Austin, Tex.

The relatively high chemical content of the Red River, particularly in its upper reaches, has been a recognized fact for many years. The search for water of good chemical quality has been one of the major endeavors of most of the municipalities in this particular area. Whereas the creation of Lake Texoma made available large volumes of water to the Upper Red River area, actual water uses have been limited primarily to power generation and recreation. Lake Texoma has become one of the most popular fishing and recreational areas of the Southwest, attracting over seven million people each year. Water quality became a subject of everyday conversation when it was learned that industries interested in reliable sources of water were passing up the Red River Basin as potential sites because of the high chemical content of the waters. As this fact became more generally recognized, there resulted a growing movement by the Red River Basin people to encourage studies and surveys to determine a course of action to improve these quality conditions. In this connection the Red River Valley Association has been quite active, and undoubtedly the authorization of a compact between the four States of Texas, Oklahoma, Louisiana, and Arkansas for apportionment of these waters among those States has added materially to the increased interest in this quality problem.

Survey Program

It is general knowledge that the chemical content of the Red River waters, particularly above Lake Texoma, is influenced greatly by natural as well as man-made sources. It had not been determined, however, just how much the natural sources were contributing to this condition nor how much the man-made sources were contributing. In order to establish more specific information along these lines, a cooperative endeavor was initiated in February of 1958 with the U. S.

Public Health Service, Region VII Office in Dallas and the Texas State Health Department, whereby a survey would be made of the Upper Red River Basin in Texas with the purpose of determining the location, type of source, and extent of chemical contribution to the waters of the Red River. Personnel was furnished jointly by the cooperating agencies. Headquarters were established in Wichita Falls in the offices of the City-County Health Unit. This particular portion of the survey continued through June 30, 1959.

In the early part of this study, problem areas were located both in oil field areas and in the upper part of the Wichita and Pease River Basins where natural pollution occurs. Care was taken to locate the precise stretches of the rivers where degradation occurs. Not only were salt springs and marshes located, but the oil field areas having poor brine disposal techniques were also spotted. During these operations, daily chloride sampling stations were maintained and readings were taken at flow gaging stations established in the area by the United States Geological Survey in cooperation with the Texas Board of Water Engineers. In this way corresponding discharge readings would supplement quality records. Where established gaging stations were not available, flow and quality determinations were made in the field at strategic locations in the Basin. As most of the sources of pollution were located, weekly sampling programs were established.

Red River Quality

A review of the water quality situation of the Red River System reveals that organic, or sewage, pollution does not appear to be a major factor affecting beneficial uses—although possibly there are certain localized areas where improvements can be made. It is evident, however, that there are areas of chemical contribution located in the upper reaches of the Red River System—in Oklahoma and Texas—which have a material effect on the acceptable quality of the water. Waters in this area are high in total solids, frequently ranging above 3,000 mg/l; over 1,000 mg/l in chlorides; and around 500 mg/l sulfate content. This poor quality water flows, with a little dilution, into Lake Texoma which serves to some extent as a "quality equalizing pond" as is evidenced by the quality of the water being discharged from the dam. In this discharge, total solids average about 1,000 mg/l; chlorides, around 400 mg/l; and sulfates, in the vicinity of 250 mg/l or less. There is, of course, dilution water entering the river system between the Denison Dam and Texarkana. At Texarkana (some 170 highway miles downstream) total solids during the period of September 1958 through September 1959 averaged somewhat less than 550 mg/l and chlorides and sulfates somewhat less than 190 mg/l.

Sources of Pollution

It is estimated that the chloride load of the Red River at Gainesville which is the upper portion of Lake Texoma, is in the vicinity of 3,400 tons per day. In one basin contributing 704 tons per day it was determined that some 362 tons per day originated as oil field brines. On this basis, therefore, it seems apparent that, in this area at least, approximately 50 per cent of the total chloride load entering the Red River is from man-made sources and the other half originates from natural sources.

With regard to the oil field brine problem, oil production in the Upper Red River Basin constitutes only about 6 to 7 per cent of the over-all statewide production. The general area of oil production in Texas in the Upper Red River Basin is relatively small compared to that area containing sources of natural pollution. According to figures which are only approximate, there are roughly 13 mgd of salt

water produced for the entire State. A reliable breakdown of disposal practices is not available but brine disposal by injection is quite common; consequently, it is not inferred that all of this water reaches water courses of the State. As is usually the case in oil producing areas, the heavy production areas are not necessarily a primary source of large volumes of salt water. Most salt water is produced from the rather old fields where the operation involves pumping as much as 80 or 90 bbl of salt water for every barrel of oil. These operations are sometimes referred to as "stripper" fields. In this particular area, however, the average mineral concentration of oil field brines is higher than it is in other areas of the State. Most of the brines in the Red River Basin will average around 100,000 mg/l chloride. Obviously, a small volume of this highly concentrated brine is capable of materially affecting larger volumes of water —for instance one pint containing 100,000 mg/l chlorides will cause a 100-mg/l increase of chlorides in 125 gal. A flow of 1 cfs for 24 hr will raise by 100 mg/l, 2,000 acre-ft of water.

From these examples, it appears theoretically feasible to reduce appreciably the mineral content of the Red River Basin water with proper control of relatively small volumes of brine. The practical application of this theory is the next phase of study.

It is becoming somewhat apparent, nevertheless, that the approach to the solution to this problem must be a joint one in which control of not only the man-made pollution must be achieved, but also some control of the natural sources of pollution must be achieved simultaneously. In pollution enforcement activities, the effect of a wastewater on a receiving stream must be proven detrimental to some of the water uses. In this area, however, it is not unusual for the natural mineral content of the water of the receiving stream to be far in excess of acceptable limits prior to the introduction of any wastes. This condition presents many interesting and unusual aspects which require solution as more pertinent data and information become available.

IV. ONE ABATEMENT PROGRAM AND WATER QUALITY OF THE OUACHITA RIVER—A TRIBUTARY OF THE RED RIVER

By G. T. Kellogg

Chief Engineer and Director, Arkansas Bureau of Sanitary Engineering, Little Rock, Ark.

The Ouachita River rises in the mountains of western Arkansas and flows southeastward across the State, finally leaving in the eastern third of its southern boundary.

In the upper reaches the water quality is excellent. Table I shows the chemical quality at Mt. Ida.

At mile 311 pollution from oil fields begin to enter the river through Smackover Creek, deteriorating the water to such an extent that the State of Louisiana threatened to invoke Public Law 660. Table II shows the conditions at Smackover Creek.

In the river at this point the resulting admixture indicates chloride contents of 192 mg/l at 3-ft depth and 5,110 mg/l at 15-ft depth (1).

A total 19,800,000 gal, equivalent to 12,500,000 lb of salt, enters the Ouachita system daily.

Arkansas Program

The State of Arkansas, recognizing its responsibility to its sister state, be-

TABLE I.—Water Quality in Ouachita River at Mt. Ida

Item	Amount
pH	7.4
Total alkalinity (mg/l)	76
Total solids (mg/l)	113
Total hardness (mg/l)	90
Carbonate hardness (mg/l)	76
Non-carbonate hardness (mg/l)	14
Cl (mg/l)	2
SO_4 (mg/l)	8.0
Ca (mg/l)	29.2
Mg (mg/l)	4.1
Fe (mg/l)	0.10
Mn (mg/l)	0

gan a program aimed at cleaning up and maintaining the water quality so that, at the Louisiana State line, it could be put to any use.

One of the first things needed was the sources of all pollution entering the river. Staff and budget limitations made it necessary to look for other sources of financing. This was obtained from federal and state funds and a consulting engineer was employed to make a comprehensive survey. All laboratory work was done by the Arkansas Water Pollution Control Commission.

The work order stipulated that all waste sources—municipal, industrial, and oil fields, were to be surveyed. A report was prepared within 10 months.

The Water Pollution Control Commission is bound to hold public hearings in the area where pollution is occurring (2). After holding these hearings and receiving all data from interested parties, the Commission then decides on a course of action. After this decision has been reached a second hearing must be held. The first hearing is called "fact-finding" and the second, a "show-cause hearing."

TABLE II.—Water Quality in Smackover Creek

Item	Amount
pH	6.8
Total alkalinity (mg/l)	48
Total solids (mg/l)	41,174
Total hardness (mg/l)	8,000
Cl (mg/l)	17,688
SO_4 (mg/l)	86
Ca (mg/l)	1,700
Mg (mg/l)	925
Fe (mg/l)	47
Mn (mg/l)	0

At the "show-cause hearing" those persons, firms, corporations, or municipalities to which the Commission contemplates issuing an order, are given an opportunity to show cause why the order should not be issued.

After this hearing the Commission may or may not issue an order as the case may be.

After receipt of the Lower Ouachita Report, hearings were held in the various areas of the river basin, followed by the proper "show cause" hearings; orders were then issued to 196 oil well operators, 4 communities, and 2 industrial establishments.

Order to Oil Field Operators

The order to the oil field operators has unique ramifications which should be of interest.

This order required all operators in the affected area to gage salt water and waste production from all wells between December 1, 1958 and February 15, 1959. Wells could be gaged by any method utilized by the Arkansas Oil Association, or by methods acceptable to the Arkansas Oil and Gas Commission. The information was known as the base volume.

The order (3) further stated that each operator was to reduce this base volume 20 per cent during the next 12 months and each succeeding 12 months thereafter. Thus, there is basically a 5-yr planned reduction of oil field wastes. The methods of reduction, whether by "shut-downs," "squeeze-ins," "reworks," abandonment, or injection system, were required to be filed with the Commission. Each well and battery plans were thus on file at their office.

A further facet of the order permitted one or more operators to join together, thereby permitting small op-

erators to merge, or unite with large operators. If any operator chose to dissolve this association, he was permitted to do so, provided he reduced his base volume 20 per cent.

Finally, the order stated that any operator failing to accomplish 20-per cent reduction within the 12-month period must automatically dispose of all his brine production immediately. A $1,000 fine was incorporated into the order and each day's offense was made a separate offense.

Evaluation of Program

Near the end of the first year field reports and surveys indicate that approximately 27-per cent reduction of salt water will be accomplished.

In 1959 the Legislature recognized the impact of the order on the oil industry and, further recognizing that future orders will most certainly be issued, passed another Act, which gives back to the oil operator his severance tax if he installs an injection system, meeting the requirements of the Oil and Gas Commission and the Arkansas Water Pollution Control Commission. However, in no event is the oil operator permitted to recover more than his cost of operation and maintenance of the injection system.

Estimates of the cost of the law to the State of Arkansas are shown in Table III.

The gradually increasing costs reflect the probable difficulty in the abatement program. Initially, the 20-per cent reductions will be gained by "shut-downs," "reworks," and "squeeze-ins." Later on these will not take care of the salt water production and, consequently, more injection systems will be needed, with increased severance tax turnbacks.

TABLE III.—Estimated Cost of Pollution Control Law

Year	Cost ($)
1959	105,000
1960	175,000
1961	240,000
1962	310,000
1963	370,000
Each calendar year thereafter	370,000

In the first year, 16 injection systems are being or have been installed and many are planned for the second year of the program.

The Arkansas Water Pollution Control Commission has established stream monitor stations in all areas affected by the order. With their previous stream data they believe that the anticipated 20-per cent reduction is actually occurring and while the cost to the state may not seem to be a large sum to others, it is a substantial sum to the State of Arkansas and is a price that shall and must be paid to provide a sister state with the water quality she desires and deserves.

References

1. Crist, M. L. and Associates, "Report of Survey of Pollution Sources-Ouachita River Basin."
2. Act 472 of the 1949 Arkansas Legislature.
3. Arkansas Water Pollution Control Commission, Order 1-58 to the Oil Industry of Arkansas (Jan. 1958).

V. THE DOWNSTREAM END

By John E. Trygg

Director, Division of Public Health Engineering, Louisiana State Board of Health, New Orleans, La.

To Louisianians being on the downstream end means that eventually the State will receive all of the water falling on the watershed, used and unused, wanted and unwanted, and that it comes both on top of the ground and in the ground.

This discussion will concern itself

with water quality as pertinent to domestic water supply and the health aspects in recreational use.

Ground Water

Ground waters are abundant and of usable quality throughout the state except in a small portion of the northern part and the seven parishes bordering the lower Mississippi River. Recharge of the aquifers are from within and without the State. Much of the State's ground water needs no treatment and in some cases artesian flow provides sufficient head so that pumps to maintain pressure on the distribution system are not needed. One such case is the City of Slidell which has an artesian well which delivers 3,250 gpm at a head sufficient to eliminate the need for pumping. This water is of top quality and chemically requires no treatment.

Industry uses a great deal of ground water, particularly in the Baton Rouge and Lake Charles areas and the ground water table has been adversely affected in these areas. The result has been that municipalities have had to lower their pump bowl settings or go to different aquifers.

Agriculture also draws heavily from the underground in the rice growing areas in South Louisiana.

Surface Water

In addition to the ground water resources, Louisiana has tremendous surface water resources which is understandable in that Louisiana has an average annual rainfall of approximately 56 in. and as previously stated it is the lowest portion of the largest drainage shed in the continental United States. The Mississippi flows along the Louisiana-Mississippi boundary and through the southern part of the State. The State is flanked on the east by the Pearl River, on the west by the Sabine and in between are the Vermilion and Calcasieu and, of course, the Red River and the Ouachita River in the Mississippi System as well as the Atchafalaya which is basically a distributary of the Mississippi. Although surface waters are used for domestic supplies in various parts of the state, only the seven lower Mississippi parishes use surface sources exclusively.

Louisiana problems in water quality are largely potential. Although surface water ranges from good quality to fair, there is no source in Louisiana that need not be treated before use in a domestic system. The major problems in treatment are those of tastes and odors. These are basically from industry sources although there are examples of heavy organic contamination by domestic sewage, particularly from the City of New Orleans where the coliform content has run as high as 1,000,000 per 100 ml of sample at water plants below the City. The Mississippi River above New Orleans where the population is more dispersed has been in better condition. Growth of population centers has been recent and treatment works are being built to match the cities' growth. The latest accomplishment in improving the quality of the lower Mississippi River water was the Baton Rouge bond election where funds were voted for not only major trunk lines for the City but for primary treatment works for all sewage.

Pollution Problems

The tastes and odors in the water are largely attributable to industry discharges to the Mississippi River in Louisiana and in the over-all river basin above the State. Some of the local sources of pollution have been difficult to cope with, particularly intermittent discharges such as those occurring from ocean vessels which may travel up the River as far as Baton Rouge.

It is believed that many problems of water pollution control in Louisiana are directly attributable to the fact

that this State has so much water. Industries have been attracted with the idea that not only will they have an abundant source of water, but that they will have abundant water for dilution.

Another matter which greatly concerns the Louisiana State Board of Health is that of heavy metals. The U. S. Public Health Service Drinking Water Standards state that there shall be no heavy metals in drinking water, and with that in mind there is concern with the discharges that may be occurring not only in Louisiana, but probably in the upper Mississippi Valley states. It is difficult to support a stand to deny permits to discharge heavy metals when an industry in making application can prove that the discharge will not be readily detected or detected at all. The question appears to be "How fast will a buildup occur and how heavy a buildup may we allow?"

Some of the major problems probably stem from the action of those who are disciples of the theory of "dilution solves all pollution." The Mississippi River with its tremendous volume would seem to be able to provide the necessary dilution but when there are many contributors and when some of the troublesome substances to a water plant are not removed naturally or cannot be removed in normal treatment processes, dilution is not the answer to pollution. There is a question as to whether a water treatment plant should also serve in the capacity of a waste treatment plant.

Although the Red River was used for a domestic source at Shreveport, Louisiana, at one time, its use was abandoned a number of years ago, and the River has not served as a source of water since then until 1959 when Bossier City completed a new water treatment plant using the Red River as a source.

In summary, Louisiana water quality problems are not the greatest in these United States, but definite and difficult problems are foreseen unless controls can be exerted to stop their development.

VI. WATER QUALITY CONTROL IN A WATER-RICH STATE

By K. E. Biglane

Executive Secretary, Louisiana Stream Control Commission, Baton Rouge, La.

Any summary report on surface and ground water resources in the State of Louisiana always produces impressive figures and startles the imagination. To any state water pollution control administrator, the vision of flowages normally averaging nearly 700,000 cubic feet per second in one day's total flow for all streams, should bring about the kind of satisfaction known only to those who have unlimited credit at the bank. Adding to this credit are dividends in the form of an average annual rainfall of 56 in. and ground water enough to cover the State to a depth of 70 ft if it were all brought to the surface. A closer look at these liquid assets, however, reveal that of the seven major river basins in the State, the stream flows in one river, the Mississippi, constitutes 83 per cent of the total average flow by its own contribution.

The state has a number of industries that use tremendous quantities of water. This quantity has been estimated in excess of 3,750 mgd. Notable among the largest users are oil refineries, paper mills, chemical plants, and sugar mills. As can be expected, most of this water, carrying waste loads, ultimately finds its way back into the river basins.

Stream Control Commission

The water quality control authority for Louisiana is the Stream Control Commission and is composed of the heads of other State boards or departments such as Health, Agriculture, Oil and Gas, Wild Life, Attorney General, and Commerce. The Commission is supplied with and makes its policies from technical data furnished by a research and survey division, the Division of Water Pollution Control, under the Louisiana Wild Life and Fisheries Commission. This research and survey group is well-staffed and equipped to carry out its functions.

Pollution Control Problems

Since the surface water from all major basins arises from outside the state, water quality control inside the state is sometimes hampered at the outset. Interstate rivers such as the Red and Ouachita Rivers in Louisiana were seasonally polluted by paper mill wastes from Arkansas. Occasional spillages of crude oil from stripper fields, together with chlorides in oil field brines from this same State have rendered the Ouachita virtually useless to Louisiana although it flows through a prime industrial area and a heavily populated section of the State. The recent positive enforcement steps taken by the Arkansas Water Pollution Control Authority have raised high hopes for the future use of this great river. Likewise, the tremendous amount of groundwork done by representatives of the four States of Arkansas, Texas, Oklahoma, and Louisiana preparing for a compact with anti-pollution considerations on the Red, has awakened new encouragement for this important river system.

A number of things make the management of surface water difficult in the State. The higher, hilly portions of the Northwest, Central, and Northeast Louisiana melt into low, marshy plains on the Gulf Coast. Waters flowing southward into these flat areas are influenced by tides and accompanying reverse flows resulting in the reuse of industrial waters, particularly cooling water, taken from these streams. This can and has brought about stacking or compounding of organic loads, salt water intrusion from the Gulf (even in the Mississippi River), and water stagnation resulting from the decay of natural organic detritus in a stream whose positive downstream flow is stymied by tidal actions from the Gulf. In these areas are large concentrations of raw sugar mills which have condenser water and other wastes discharges approaching 200,000 gph and containing dissolved sugars from entrainments. Pollution of water bodies receiving this waste was the rule rather than the exception prior to 1957. In-the-mill correction for sugar entrainment and impounding of certain mill wastes high in BOD, resulted in a decrease of from 87,000 lb BOD/day in 1954 to 20,000 lb BOD/day in 1957 in one short stretch of Bayou Teche. This particular stream is cited for it was the worst polluted area in the State during the grinding season. Other similarly affected streams have been unburdened in a like manner but the lack of continuous flow to the Gulf prevents a maximum corrective action.

Results

Industrial expansion on the Mississippi River has brought forth water quality maintenance concepts which were found only by intensive researches and surveys of the river itself. Because the river serves as a source of drinking water for almost a million people below Baton Rouge, the Stream Control Commission, in conjunction with the State Board of Health, adopted a policy of not allowing any increase in raw sewage discharges between Baton Rouge and New Orleans beginning in 1956. Among the improvements by other towns and industries in this stretch of river, this policy

has, in part, resulted in a 22-million dollar bond issue being passed by the City of Baton Rouge to construct sewage collection systems and treatment plants.

On a yearly basis, the river normally flows an average of more than 500,000 cfs and this should prevent the possibility of septicity from organic wastes. The Commission bases industrial waste dilutions on low flow averages of 100,000 cfs. Taking into account the chloride loads contributed by upstream states, and industries in Louisiana, no additional oil field brines were allowed to be discharged into the Mississippi River beginning in 1956.

The restriction of those waste streams high in taste and odor components has resulted in their underground disposal by two oil refineries and one chemical plant. Other treatment measures applied to these particular wastes are: specific recovery for salable fractions, stream stripping and flashing into superheated stack gases, chemical springing for on-the-site neutralization, and treatment by biological oxidation.

In summary, one can readily appreciate the fact that although Louisiana has a great potential supply of water, some basins are in geographical terrains that demand good pollution abatement practices. Other basins with tremendous flows can still be affected by industrial wastes and these wastes must be isolated and individually handled.

MEETINGS OF INTEREST

July 18–22	**National Association of Sanitarians,** Jack Tar Hotel, San Francisco, Calif. Nicholas Pohlit, c/o University of Denver, Denver 10, Colo.
Aug. 14–17	**American Public Works Association,** Manhattan Hotel and New York Coliseum, New York. Robert D. Bugher, Executive Director, 1313 East 60th St., Chicago 37.
Aug. 22–27	**Seventh International Conference on Coastal Engineering,** The Kurhaus at Scheveningen, The Hague, Netherlands. Prof. J. W. Johnson, University of California, Building 159, Richmond 4, Calif.
Aug. 29–31	**Symposium on Water Quality Data Collection and Utilization,** Robert A. Taft Sanitary Engineering Center, 4676 Columbia Parkway, Cincinnati 26, Ohio.
Sept. 11–16	**American Chemical Society,** New York, N. Y. American Chemical Society, 1155 16th St., N. W., Washington 6, D. C.
Sept. 20–23	**United States Civil Defense Council,** Lexington Hotel, Minneapolis, Minn. Elliott R. Jackson, Municipal Auditorium, Atlanta, Ga.
Oct. 2–9	**Inter-American Association of Sanitary Engineering,** Hotel Carrasco, Montevideo, Uruguay. F. W. Montanari, 414 Walnut St., Room 302, Cincinnati 2, Ohio.
Oct. 10–14	**American Society of Civil Engineers,** Statler Hotel, Boston, Mass. W. H. Wisely, ASCE, 33 West 39th St., New York 18.
Oct. 18–21	**First Effluent and Water Treatment Convention,** The Seymour Hall, London, W. 1., England. Thunderbird Enterprises Ltd., 140 Cromwell Rd., London, S. W. 7, England.

THE OPERATOR'S CORNER

SURFACE PREPARATION *

By Sheldon Dunning

Sheldon Dunning, Inc., Seattle, Wash.

First comes the surface preparation, then comes the protective coating. It's the old story of the "weakest link"; the coating cannot form a strong bond with the surface if there is something beneath the coating weakly bonded. Dirt, rust, scale, oil, moisture, or other loose materials provide a weak foundation and cause loss of adhesion. Impurities, such as oil or water, can prevent adhesion even when present in invisible quantities. Besides preventing adhesion, some impurities, such as rust, scale, or dirt, contribute to breakdown of the coating by drawing water through it, causing blistering and underfilm corrosion of metal.

Steel is the most widely used structural material, and steel surfaces are the ones most frequently encountered in protective coating applications. The major problem in preparing steel is the removal of all scale and rust.

Scale (sometimes called mill scale or blue scale) is a hard, blue-black layer formed on steel sheets during manufacture. It often adheres tightly to new steel, but usually loosens with age due to the difference in the coefficients of expansion. If a coating is applied over scale, it also will come loose when the scale loosens. Scale is lower than steel in the galvanic series and accelerates corrosion; it must be completely removed for best results.

Rust is familiar to everyone. It varies in color from bright red to deep brown, and may be loose and powdery or hard and brittle. In any case, it provides a weak foundation, contributes to breakdown of a coating applied over it, and promotes further corrosion.

In the sewage field, hydrogen sulfide reacts with iron in the presence of moisture, but with a limited oxygen supply. Here, the hydrogen sulfide forms iron sulfide, which in turn reacts with water to form ferrous hydroxide as a hydrated iron oxide. With the addition of water and oxygen, the ferrous hydroxide can be converted to ferric hydroxide, which can be dehydrated to the ordinary ferric hydroxide or rust. If proper surface preparation of the steel is not effected, small amounts of water-soluble hygroscopic salts may be left on the surface of the metal to be coated. If this is the case, and since all organic coatings can be considered to be semipermeable membranes, moisture vapor can pass through the film and be adsorbed by the water-soluble salts on the surface of the metal, creating a concentrated solution at that point. From then on, the process of osmosis will take over and pass water through the coating,

* Presented at the 26th Annual Meeting, Pacific Northwest Pollution Control Assn.; Coos Bay, Ore.; Oct. 29–31, 1959.

creating blisters and, eventually, coating disruption.

Even though the surface is brought down to a gray metal, it is still possible for sulfides to be left on the surface. In this case, several procedures may be used to remove the possibility of an area of poor adhesion or a continuance of the sulfide reaction underneath the film. Where sulfides alone are the problem, it is a good idea to wash the clean metal surface with water and allow the entire area to thoroughly oxidize. This aids in oxidizing the remaining sulfides to iron oxide, which then can be removed by a second, fast blasting operation. Another method, especially where high humidities are a factor and it is desirable to protect the surface of the steel from all moisture, is to flame-treat the clean surface, after which it can be given a light blast to bring out the gray metal. For best results, rust must be completely removed.

The methods most widely used in industry for removing scale and rust are blast cleaning, pickling, and mechanical and chemical cleaning.

Blast Cleaning

Blast cleaning is the best method for cleaning steel because it is effective in removing scale and rust, and it roughens the surface to provide an anchor for the coating.

Ideally, blast cleaning of steel should completely remove all rust and scale and result in a surface with a uniform, light-gray color with no black spots, rust spots, or shadows. In actual practice, however, the degree to which the surface is cleaned by blasting varies considerably, depending on the rate of cleaning, quantity of air, and type of abrasive.

To obtain the desired result, it is essential to know what the quality of surface must be. To this end, the Steel Structures Painting Council (1) established standards for different levels of blast cleaning:

1. Blast Cleaning to "White" Metal. All traces of rust, scale, old paint, or other foreign matter are removed, producing a uniform, light-gray finish.

2. Commercial Blast Cleaning. All rust, scale, and other foreign matter are removed, but not all the embedded base of the mill scale or gray oxide binder between the scale and steel. Dark streaks often appear in the surface after blasting is completed.

3. "Brush Off" Blasting. All loose rust and scale are removed, but not tightly adhering mill scale and rust.

Regardless of the standard of blasting specified, the same procedures are followed:

A blasting setup includes the abrasive, which may be sand, grit, or shot, compressed air, hose, nozzle, and pot. The abrasive is loaded into the pot—a closed tank of about 50 to 100 gal capacity—and high pressure air is led to a mixing chamber in the bottom. Air picks up a regulated amount of abrasive and carries it at high velocity through a hose leading to the blasting nozzle. The nozzle directs the stream of air-borne abrasive to the surface.

The various types of abrasives which are used perform differently and produce characteristically different types of surface pattern. The pattern or profile resulting from blasting is extremely important in its effect on coating performance. If the surface is too smooth, there will not be an adequate "anchor" for the coating. If the surface is too rough, sharp pinnacles of metal are likely to project through the coating and remain unprotected.

Some of the more frequently used abrasives and their characteristics are as follows:

1. Sand is probably the most widely used because it is readily available in nearly all locations. It is available in a wide range of particle sizes, rang-

ing from 8 mesh to very fine particles which will pass through an 80 mesh screen. Ordinarily, if sand is coarser than 16 mesh, U. S. Sieve Series, it tends to hammer the surface without getting into small depressions.

It is important to use sand that does not produce excessive dust. Dirty sand and even some types of clean sand break down on hitting the surface and produce large volumes of dust. This obscures the surface and causes extra work in removing dust after blasting.

2. Steel grit is sometimes used in place of sand. Grit particles are hard, angular-shaped pieces of cast iron, malleable iron, or steel with sharp edges. Grit has several advantages over sand: it produces less dust, cuts faster, and can be reclaimed for future use. Its disadvantages are higher cost and a tendency to roughen the metal excessively. Coarse grit will cut deeply into the surface, leaving points of metal sticking up. After the coating is applied, it tends to run off these high points, leaving them bare, so several extra coats are required to build up a satisfactory film on such a surface.

3. Steel or iron shot may also be used as an abrasive. But shot-blasting is relatively inefficient because the particles are round and smooth, and tend to hammer foreign matter into the surface without removing it. Sand or grit blasting produces a better surface.

Conventional sandblasting procedure is to use dry sand and dry air; however, "wet" blasting procedure is sometimes used because dust is reduced. In wet blasting, water is injected at the nozzle or it is mixed with sand in the pot. In this process very little dust is produced, but it results in a surface covered with mud which must be washed off. Phosphoric acid is frequently added to the wash water to reduce the rate of rusting.

Preparation by wet blasting is not recommended for most protective coatings because the surface always rusts before the coating is applied and phosphoric acid produces a powdery surface which must be brushed off.

Many sandblasters believe they need only remove loose scale and rust; they often say that tightly adherent scale is "in the steel" and can't be removed. It can be removed, and must be removed when a "white" blast is specified.

Removal of dust is extremely important. If dust remains, it prevents the coating from contacting the metal and results in lack of adhesion.

As sandblasted surfaces rust rapidly, the prime coat should be applied the same day the surface is blasted. *Do not allow the surface to stand overnight.*

Pickling

Acid pickling is frequently used to clean steel objects small enough to be immersed in a tank of pickling solution. It is often preferred to blast cleaning in a production line setup because less labor is required and no dust is created. A typical procedure involves the following steps:

1. Degrease with solvent such as xylol.
2. Immerse in hot acid until all scale and rust are dissolved. A suitable solution is 20-per cent sulfuric acid at 180°F.
3. Rinse in hot water.
4. Immerse in 5-per cent phosphoric acid solution to reduce the rate of rusting. (When rinsed off with water, this does not form the powder mentioned under sandblasting.)
5. Rinse with hot water and dry.

The coating must be applied before the steel commences to rust, preferably as soon as it is dry. It should not stand more than four hours.

This process has given satisfactory results in some cases; however, it is not entirely reliable because solutions

become contaminated, and many proprietary pickling compounds of unknown composition and properties are used commercially. Therefore, acid pickling is not recommended as a means of metal preparation where a coating is to be used as a tank lining.

Mechanical Cleaning

Mechanical cleaning processes used where blast cleaning is impractical include chipping or scraping, sanding, and wire brushing. These methods are not satisfactory when the coated surface is to be continuously immersed, but may be adequate if it is exposed only to fumes, spillage, or occasional washing.

Chipping or scraping is the best method of mechanical cleaning of rough surfaces if it is done carefully. The disadvantages of this method are that it is extremely slow, and it tends to roughen the surface excessively. However, it is the best mechanical method for preparing pitted surfaces.

The best procedure is to use a pneumatic chipping hammer on heavy rust and tight scale. Loose rust can be chipped or scraped by hand. Power-driven sanders should follow scraping to complete the cleaning. Oil or grease should be removed with solvents.

Sanding is not usually effective on heavy or hard deposits of rust and scale. It is effective, however, on moderately rusty metal or following cleaning with a chipping hammer.

Wire brushing is in most cases a useless procedure, but it is still widely used industrially. When wire brushing by hand, the average workman is unable to apply continuously enough force to the brush to remove anything but very loose material. The brush tends to skip over the surface from one high spot to another, without affecting foreign matter in pits or depressions and without removing tight rust or scale. Power brushing, using a rotating wire wheel, is only a slight improvement. A power-driven brush still won't remove tight rust or scale, and the rotating action tends to produce a smooth polished surface which is not conducive to good adhesion. Wire brushing is not usually recommended by coating manufacturers.

Choice of Methods

As previously indicated, blast cleaning is the best method of preparing steel surfaces. There are circumstances, however, where this procedure is not practical or economical and a substitute method is desired. In these cases, the most practical method will depend on the exposure, the type of finish coat to be used, and the present condition of the surface. Each case must be analyzed individually, but a few samples are listed in Table I.

A wide variety of cleaning materials and methods are used in chemical cleaning. Surface preparation can be accomplished by solvent wiping, vapor degreasing, alkali or steam cleaning, and emulsion cleaning to remove

TABLE I.—Surface Preparation for Various Conditions of Use

Surface Preparation	Coating Exposure		
	Continuous Immersion	Alternate Wet and Dry	Dry Fumes
White blast	Ideal	Ideal	Ideal
Commercial blast	Trouble breeder	Safe compromise	Safe compromise
Brush-off blast	Trouble breeder	Trouble breeder	Safe compromise
Pickling	Trouble breeder	Safe compromise	Safe compromise
Power-tool cleaning	Trouble breeder	Trouble breeder	Safe compromise
Hand cleaning	Trouble breeder	Trouble breeder	Depends on quality of cleaning

grease and other surface oils prior to removal of rust and scale. In all methods of solvent cleaning, except vapor degreasing, the solvent soon is contaminated with the removed dirt, oil, etc., which after a short time is redeposited on the surface. To avoid this, solvents must be renewed constantly.

Structural Details

Protective coatings generally cannot be applied successfully over sharp corners or in narrow cracks. When applied over sharp corners or points, the coating draws back from the edge during drying. No matter how carefully it is applied, the coating will be thin on all sharp edges and projections. Cracks present another problem because of the difficulty of getting the coating into a narrow opening.

For complete protection, as in lining a tank, sharp edges and cracks must be eliminated:

1. Rough welds and other sharp edges must be ground smooth.
2. Weld splatter must be knocked off with a scraper or a chisel.
3. Seams joined with skip welds must be rewelded with a continuous bead.
4. Baffles must be welded on both sides.
5. Rivets must be tight.

If additional welding is required or if grinding is necessary, it should be done before sandblasting.

Concrete

Concrete surfaces are generally of three types: placed against forms, such as concrete walls; hard-trowelled, such as floors or sidewalks; and "gunited," produced by spraying.

Formed Surfaces

Concrete placed in forms is the most difficult to prepare satisfactorily because there are likely to be rough spots and pits in the surface. Rough spots and projections must be smoothed by scraping; then the holes and pits in the surface must be filled by "sacking." Finally, the entire surface must be acid etched. The procedure is as follows:

1. Scrape off sharp projections with trowel or scraper.
2. Wet surface and allow excess water to drain off.
3. Mix a mortar, using one part cement and two parts sand with enough water to form a creamy paste.
4. Rub mortar into pores, pits, and holes with a coarse cloth cement sack or wood float.
5. Wipe off excess mortar so that a smooth, dense surface is obtained.
6. After sacking, keep the surface damp for several days to cure the mortar.
7. Etch entire surface with a mixture of one part hydrochloric (muriatic) acid and two parts water.
8. Spread acid with brush or garden spray. Wet surface thoroughly. Solution will bubble vigorously for ¼ to ½ min as concrete is etched. When bubbling ceases, acid is neutralized. *Caution:* Workmen should wear rubber gloves when applying acid. If spilled on the skin, acid should be washed off immediately with water.
9. Wash surface with water. Brush during washing to remove salts.
10. A properly etched surface is slightly granular and free from glaze. If glazed areas remain, repeat the etching procedure.
11. Allow the surface to dry completely before applying the coating.

Trowelled Surfaces

Trowelled concrete is usually much smoother and easier to prepare since

there are unlikely to be any air pockets or holes. To clean the surface and remove any glaze, it need be etched only. It should be treated with a mixture of one part hydrochloric (muriatic) acid and two parts water, washed with clean water, and dried. If the surface is still polished after this treatment, the etching must be repeated. A properly etched surface should have a definite "tooth" or perceptible roughness when rubbed with the fingers.

In some cases, concrete floors are treated with hardeners to produce a denser and smoother surface. The application of coatings over hardened concrete is not reliable and should be avoided unless test applications show that satisfactory adhesion can be obtained. Sometimes it is necessary to etch a hardened floor with concentrated acid to remove the glaze.

Gunited Surfaces

Gunited concrete is made by spraying mortar from a nozzle. When the proper thickness is attained, it is usually smoothed off with a wooden float or trowel.

The finish is dense as is hard-trowelled concrete, and if smooth, it can be prepared by acid-etching. If it has not been trowelled, it may be necessary to plaster the surface with cement mortar, as in sacking poured concrete.

Where concrete has been badly corroded by sulfides, sandblasting is the only suitable method of preparation. The concrete should be blasted back to a dark gray surface. There are three colors to be noticed in concrete which has been subjected to sewage conditions: First, there is the white color associated with the soft calcium sulfate deposit on the surface. Below this layer, the concrete will turn yellow. Next, there is a very sharp line of demarcation between the yellow and the normal dark gray of good concrete.

It is necessary to go beyond the yellow band to satisfactorily prepare concrete because the yellow area will continue to disintegrate, and if a coating is applied over it, it will fall away as the concrete base disintegrates. In blasting to the necessary depth, the concrete will become very rough, which will necessitate resurfacing by either plastering or guniting to bring it back to its original thickness. Following this, the normal preparation for concrete is recommended.

Reference

1. "Steel Structures Painting Manual." Vol. 2. Steel Structures Painting Council, Pittsburgh, Pa. (1955).

PRINCIPAL PROTECTIVE COATINGS FOR WASTEWATER WORKS *

By Herman A. Knoedler

Western Division Manager, Inertol Co., Inc., San Francisco, Calif.

The coatings normally used to protect steel or concrete or both in municipal and industrial waste treatment works can be divided into the following classes:

1. Coal tar pitch coatings,
2. Asphaltic coatings,
3. Coal tar epoxy coatings,
4. Oil paints,
5. Phenolic paints,
6. Alkyd paints,
7. Epoxy ester paints,
8. Chlorinated rubber paints,

* Presented at the 26th Annual Meeting of the Pacific Northwest Pollution Control Assn.; Coos Bay, Ore.; Oct. 29–30, 1959.

9. Butadiene styrene paints,
10. Vinyl copolymer paints,
11. Silicone paints,
12. Epoxy resin coatings,
13. Grease coatings, and
14. Emulsion paints.

A number of other types are available, but the ones mentioned above are sufficient for a general survey.

Bituminous Coatings

Bituminous coatings are based on coal tar pitch or asphalt. They range from cut-backs and fiberized mastics to hot coatings applied in the molten state by mopping, dipping, pouring, or spinning.

1. *Coal tar pitch coatings* are the most water-resistant compounds known. Their resistance to weak mineral acids, alkalis, salts, brine solutions, hydrogen sulfide, and other aggressive chemicals is remarkable. They give more value per dollar than any other protective coatings, but have certain limitations. The color is black and the thinner coatings tend to alligator in the sun. They are strong taste and odor producers and cannot be used on surfaces in contact with drinking water. Therefore, they should be used only below sewage level or on interior surfaces, for instance in pump pits where the black color doesn't matter and the sun doesn't strike.

Coal tar pitch coatings are available in different types which give different film thicknesses and should be selected according to the amount of protection needed. Concrete in most cases can be adequately protected by three coats of a coal tar pitch solution. Metal, however, needs a much heavier coating.

The heavier grades are fiberized or jelled types of coal tar solutions which can be applied at a low square footage per gallon without sagging, giving increased film thickness per coat.

2. *Asphaltic coatings* are not quite as water resistant as coal tar coatings, but more weather resistant and do not alligator in the sun. Since they do not impart any taste to drinking water, they are very valuable coatings for protecting submerged concrete and steel in water works. They are manufactured in different types providing different film thickness. Submerged concrete in water works can be adequately protected with two coats of a suitable asphalt solution. Steel, submerged or not submerged, however, needs one of the heavier grades to prevent corrosion.

3. *Coal tar epoxy coatings* are mixtures of a coal tar pitch and epoxy resin, cold-cured, with an amine.

The remarkable resistance of coal tar pitch to the disintegrating action of water is well known. But they are not really tough, alligator in the sun, and are not resistant to animal or vegetable oils, household detergents, or solvents. The combination of coal tar pitch and epoxy resin combines the best features of both, and a properly formulated coal tar epoxy coating has truly outstanding characteristics. Adhesion and toughness are excellent, and the abrasion resistance is of the highest order.

The resistance to water, weak acids, detergents, and mineral, vegetable, and animal oil is very good. Resistance to weak solvents such as mineral spirits, diesel oil, gasoline, jet fuel, and lubricating oil is also good. Very strong solvents like xylol, toluol, and ketones attack the coating, but the coal tar epoxy is far more resistant to these solvents than the coal tar pitch itself. In addition, coal tar epoxies overcome the alligatoring of coal tar coatings and a thickness of 16 mils can be easily achieved in two coats.

Coal tar epoxies are two-component systems which have to be mixed just prior to use. They are black in color, but interior surfaces painted with coal tar epoxies can be painted over with a colored, cold-cured epoxy coating wherever the black color cannot be tolerated.

Even though coal tar epoxies are fairly new, they have already proved themselves.

Oil Paints

Oil paints consist of a dispersion of one or more pigments in drying oils. The oils predominantly used are raw and bodied linseed oil. They form soft, elastic films which are very weather resistant and fail gradually by erosion, producing an excellent foundation for recoating. Their abrasion, alkali, and water resistance is very poor. The only place for oil paints in wastewater treatment plants is on large wooden structures where a regular house paint is called for. Sewage treatment plants must use a house paint which is lead-free because hydrogen sulfide will turn any lead compound into lead-sulfide which is black.

Phenolic Paints

Phenolic paints are a combination of pigments and a phenolic varnish. Their properties vary with the type of phenolic resin and the type of oil, and also with the amount of oil present. Where outdoor durability is the desired feature, long-oil varnish, that is, a varnish containing plenty of oil, will give better performance. Wherever chemical and water resistance is essential, a short-oil varnish, that is, a varnish with a small amount of oil, should be selected. Phenolic paints may be used in severe industrial atmosphere and for protecting steel submerged in water.

Alkyd Paints

Alkyd paints are excellent for structural steel and machinery. There are different types of alkyd paints which differ in the amount of oil used in manufacturing this synthetic paint. Their chemical resistance is good enough for most atmospheric conditions, and their durability, gloss retention, and toughness are remarkable. Their water and alkali resistance, however, is rather low, and they should not be used on bare concrete or on submerged structures. They are quite resistant to normal condensation as long as they are not used in places where the paint never has a chance to dry.

Epoxy Ester Paints

Oil-modified epoxy paints combine the excellent adhesion, toughness, abrasion resistance, flexibility, high gloss, and durability of an alkyd with the chemical and water resistance of a short-oil, 100-per cent phenolic varnish. Because of the oil present, they do not approach the chemical resistance of the epoxy resin itself. They are inferior to chlorinated rubber and vinyl paints in alkali resistance and under conditions of constant submersion.

Epoxy ester paints cover a much wider field than either chlorinated rubber or vinyl paints because they are applied as easily as ordinary paints. They are non-lifting, which makes painting over old oleoresinous enamels possible.

Chlorinated Rubber Paints

Chlorinated rubber paints combine acid, alkali, and water resistance to an exceptional degree. Acids, alkalis, salts, brine solutions, alcohol, gasoline, mineral oil, aggressive fumes, constant condensation, and water show no effect. They are not resistant, however, to animal and vegetable oils or grease. Green concrete can be painted with chlorinated rubber paints without danger of their being saponified by free lime.

Not all colors can be furnished for sewage treatment plants because hydrogen sulfide reacts with some pigments and changes their color. All white lead pigments, chrome yellow, chrome orange, and chrome green are darkened by hydrogen sulfide. Flat chlorinated rubber paints make excellent exterior masonry coatings on concrete, brick, stucco, and asbestos-cement shingles. They combine outstanding lime resistance with excellent weather-

ing properties. They can be applied, however, only on firm, solid masonry surfaces which have no tendency to crumble or spall.

Butadiene Styrene Paints

Butadiene styrene paints show good acid, alkali, alcohol, mineral oil, and water resistance. Their resistance to vegetable and animal oil and fat is good, and much better than that of chlorinated rubber. Their water resistance is inferior, and they are not as suitable as chlorinated rubber paints for total submersion. They make excellent concrete floor enamels. They are inferior in outdoor durability and gasoline resistance, but superior in fat resistance. Almost any aged paint can be painted over with butadiene styrene paints without lifting.

Vinyl Copolymer Paints

Vinyl copolymer paints are at least as resistant as chlorinated rubber coatings, and in addition they withstand exposure to animal fats and vegetable oils. They can be used in treatment plants to beautify and protect submerged concrete where a black color is objectionable. Since these coatings are not affected by grease, they can be used in aeration tanks in plants where grease and fat are present. Chlorinated rubber paints would be destroyed under these conditions because they are soluble in fats.

Silicone Paints

Water repellents based on silicones penetrate deeply into the pores of masonry, lining the walls of each pore with a very thin water-repellent film. This thin film which is invisible and does not change the color or texture of the masonry surface prevents absorption of water. Spalling caused by freezing will be largely eliminated and efflorescence caused by the leaching out of soluble salts in common bricks will be prevented. Staining and spotting also will be diminished. Silicone water repellents, however, are not waterproofing agents and will not stop water under pressure. On cinder blocks where pores are very large, a cement wash coat should be applied first to fill the pores. A treatment with a silicone water-repellent minimizes peeling of interior paint because much less water will pass through the masonry to push paint from interior walls.

Epoxy Resin Coatings

Cold-cured epoxy compounds make up one of the most interesting protective coating systems. It is a two-package system with limited pot life after mixing. This system is finding application where the resistance of a baked-on coating is desired, but the facilities for baking are lacking or the structures involved do not lend themselves to the baking process. Ferrous and non-ferrous metals, concrete, and wood can be protected with this system which combines excellent adhesion with very good abrasion and impact resistance and outstanding durability in extremely corrosive and humid atmospheres. The system can be used for equipment, walls, ceilings, machinery, and tanks. It may lift other types of coatings, therefore, lifting tests should be made before using. Interior surfaces painted with black coal tar epoxies can be painted over with a colored, cold-cured epoxy coating.

Grease Coating

Grease coatings consist of petroleum products to which rust-inhibiting compounds have been added. They are easily applied by unskilled labor and do not require thorough surface preparation. Grease coatings are semi-drying; they stay sticky, should be confined to surfaces not in contact with clothing, and not walked upon.

Emulsion Paints

Coal tar emulsions differ from coal tar solutions in that the coal tar pitch is dispersed in water instead of dis-

solved in a solvent. The film formed after the emulsion breaks is more porous than the film laid down from a solution. On concrete, a coal tar emulsion gives good protection. On submerged steel, however, the durability and length of service of a coal tar emulsion is definitely less than that of a heavy coal tar solution.

In enclosed areas where adequate ventilation cannot be provided, a coal tar emulsion which does not contain any annoying solvent is preferred over a coal tar solution. Concrete which cannot be dried completely also calls for a coal tar emulsion.

Since coal tar emulsion may give a taste to water, it is better not to use it where it will come in contact with drinking water.

INSPECTING PAINT COATINGS *

By Sidney S. Lasswell

Engineer, Cornell, Howland, Hayes & Merryfield, Corvallis, Ore.

The success of nearly every paint system depends on many variables, the most important of which are the type of paint selected for the exposure conditions expected, the quality of the paint, the surface preparation, and the procedures used for applying primers and all subsequent coats making up the paint system.

Paint Type and Quality

Most individuals responsible for preparing paint specifications and making paint purchases must rely on the experience and recommendations of reputable paint manufacturers. As a result, purchasers generally specify the product desired by its trade name. If the purchaser makes the conditions of exposure clear to the paint company's representative, he usually can be assured that the paint recommended, if properly applied over a suitably prepared surface, will give satisfactory protection. Only in the case of a large municipality or federal and state agencies can the practice of competitive bidding on paint procedures be justified, since this method of purchasing paint generally will require a thorough program for determining compliance with paint specifications. A program of this type is extremely complex and should be attempted only by individuals completely familiar with all phases of paint manufacture. It can be said that such a program is beyond the scope of most users of paint who specify particular protective coatings by brand name or on a "similar or equal" basis.

Field Inspection

Surface preparation and paint application offer the greatest area for poor workmanship. They are the points where field inspection is most important. But too often compliance with the manufacturer's directions and the specifications is left to the painting contractor. Unfortunately, the failure to provide adequate field inspection has been used by some paint contractors to their own advantage. Questionable practices by a few, generally put pressure on the well-intentioned to cut corners to meet competition. The result is a lowering of the quality of painting for everyone. The problem is often magnified by incompetence and lack of knowledge on the part of the painters themselves. Rarely do painters have detailed knowledge of the materials they use, and this is particularly true in the case of the

* Presented at the 26th Annual Meeting, Pacific Northwest Pollution Control Assn.; Coos Bay, Ore.; Oct. 29–31, 1959.

newer paints. It is also the usual case that the men actually performing the work will be unfamiliar with directions for the application of the paint.

To compound this problem, paint bidding procedures many times seem to be based on the assumption that the owner will not enforce the terms of the specifications as they apply to surface preparation, number of coats, and final thickness of the paint. To meet competition, the bid price is reduced, and the finished product suffers accordingly. This laxity in carrying out the requirements for correct surface preparation and other important application procedures is quite general in the industry and can be controlled only by a rigid system of on-the-job inspection.

The importance of inspection during the painting process has not been emphasized sufficiently, despite the fact that painting is probably the greatest single maintenance item around treatment plants and pumping stations. In the past several years, however, there has been a general upswing in the quality of the specifications for paint application procedures and in the providing of qualified inspection personnel. To further this trend, a detailed treatment of the relationships of exposure, materials, and surface preparation, including field inspection, has been covered in considerable detail in Volumes 1 and 2 of the "Steel Structures Painting Manual" published by the Steel Structures Painting Council, 4400 Fifth Ave., Pittsburgh 13, Pa. The recommendations contained in these volumes are valuable to anyone concerned with paint and its application and should serve as a basis for a general upgrading of inspection and painting procedures throughout the country.

Quality Control Measurements

As a further aid to the field inspector, three types of devices are available for quality control of protective coatings in the field. These are: (*a*) the dry-film gage for measuring the thickness of coatings applied over a magnetic surface such as steel, (*b*) the wet-film gage for measuring the thickness of each coat of material as it is applied over any surface, and (*c*) the electrolytic quality meter which utilizes the change in electrical resistance of a coating to detect poorly coated areas.

The ultimate corrosion protection of any protective coating is directly related to the permeability of the specific paint and the thickness of the dried film. The thickness of a paint coating is measured in mils. A mil is $\frac{1}{1000}$ in. For comparison, $\frac{1}{64}$ in. is equal to approximately 15.5 mils and $\frac{1}{32}$ in. equals 31 mils. While the paint industry has long recognized the importance of the final thickness of the protective coating, it has been the almost universal practice to specify only the number of coats to be applied and the coverage rate in sq ft/gal. Because of the tendency of painters to overthin paint and to exceed the spreading rate, most paint systems specified on this basis do not achieve the required thickness and, thus, do not provide the protection desired. To combat this, it is now recommended that paint system specifications state the minimum number of coats and also the required finished dry-film thickness, regardless of the number of coats required to achieve it.

Dry-Film Thickness

The measurement of the dry-film thickness of coatings is probably the most valuable field measurement that can be made, and the dry-film thickness gage most widely used is a magnetic type operated electrically or by a permanent magnet. These gages measure the thickness of nonmagnetic coatings which have been applied over surfaces of iron or steel. Probably the most widely used gage is the Elcometer available from Gardner Laboratory, Inc., Bethesda, Md. This particular unit requires no batteries, as it op-

erates with a permanent magnet. It retails for approximately $75. Other gages include: (*a*) General Electric Company's Type B thickness gage, which operates on 110-v a-c; (*b*) the General Electric permanent-magnet thickness gage; and (*c*) the Gardner penetrating-needle thickness gage. This last gage differs from the others in that it must penetrate the surface of the paint to measure the thickness while the other gages do not harm the surface in any way.

All of these instruments, if used in accordance with the manufacturer's directions, will give reasonably accurate and reproducible results. Omission of coats, excessive use of thinner, and other short cuts not visible in the finished job can be detected through the reduced film thickness the gage will reveal.

Wet-Film Thickness

Wet-film thickness gages are designed to measure the thickness of a wet film of paint. Since the dry-film thickness gages can be used only on a magnetic surface, it is necessary to use a penetrating-needle type micrometer depth gage on nonmagnetic surfaces or control the application of the paint by means of wet-paint thickness gages.

Suitable instruments for measuring wet-film thickness are: (*a*) the Interchemical Gauge sold by Gardner Laboratory, Inc., Bethesda, Md., which retails for approximately $65; and (*b*) the Mardudin Gage, as manufactured by the K-D Company of Palo Alto, Calif. The first gage is simply rolled over the surface of the wet paint and the thickness of the newly applied wet film is read directly in mils. The second gage is held perpendicular to the surface and pressed into the wet paint until the gage rests on the base material. The gage is then withdrawn and the deepest tooth having paint on it is noted and the wet-film thickness is read directly, again in mils. The spreading rate of any paint can be easily converted to the theoretical wet-film thickness by dividing the spreading rate into 1,600. For instance, a spreading rate of 400 sq ft/gal would equal a theoretical wet-film thickness of 4 mils. This equation is reasonably valid if the surface being coated is quite smooth and nonporous, no appreciable evaporation of solvent takes place in the wet film before thickness measurements are made, and the actual paint application method involves no appreciable loss of material. In practice, however, actual wet-film thickness for any given spreading rate can be expected to be considerably less than the theoretical, sometimes by as much as 50 per cent. Nevertheless, the wet-film thickness gage, when used with discretion, can be very helpful in that its very appearance makes workmen more careful. Its use also has the advantage of catching errors before correction is too difficult to make; thus it helps to eliminate extra coats.

Continuity and Electrical Resistance

It is generally agreed that there is a definite relationship between the conductivity of a coating and its durability. Normally, when comparing materials of similar type, the coating having the higher conductivity likely will be the least durable.

In some environments, such as a mild rural atmosphere, there is little need for concern over slight defects in the moisture resistance of coatings; but for chemical plants, refineries, marine structures, bridges, or in environments where the exposure is severe, a high level of coating continuity is necessary if the maximum protective value is to be realized.

In the past, coal-tar enamel and asphalt-type coatings were frequently required to be free of "holidays" or thin spots when checked with a high-voltage spark tester. This instrument is very effective and consists of a wire brush operating on a voltage of between 8,000 and 10,000. The brush is

drawn over the coated surfaces with the bristles in direct contact with the coating. A pinhole or thin spot in the coating manifests itself by a spark which can be seen and heard.

With the development of heavy-duty coatings of only a few mils thick, however, the use of high voltages becomes a questionable practice. In many instances, as the thickness of the coating decreases, it becomes increasingly vulnerable to puncture by the high-voltage spark. This shortcoming has led to the development of low-voltage systems utilizing voltages of 500 or less. The theory is that defects in coatings allow moisture to penetrate and this increases the conductivity of the coating. This increased conductivity then is measured or otherwise detected.

Low-voltage detectors generally consist of a galvanometer or an ammeter or some other current-detecting instrument connected to a source of power. The surface to be tested is contacted with a sponge saturated with an electrolyte, usually water. The instrument then responds instantly to changes in coating resistance by an audible change in frequency or by indication on a meter. These low-voltage testing devices can be divided into low-sensitivity and high-sensitivity instruments. As a practical matter, the low-sensitivity devices are adequate for general atmospheric exposures where severe marine or chemical corrosion is not a problem. The high-sensitivity instruments should be used on surfaces which will be immersed where exposure is severe.

A suitable low-voltage instrument commonly used is the K-D Bird-Dog paint-flaw detector. It retails for approximately $90, including the case and accessories, and is manufactured by the K-D Company, Palo Alto, Calif. A second meter is also made by the K-D Company and is known as the Paint-R Meter.

Conclusions

Wet- and dry-film thickness gages and instruments for measuring coating conductivity and continuity are valuable additional tools with which the inspector can check and control the application of paint in the field. These instruments do not eliminate the need for proper surface preparation or paint handling, but they do give a physical indication of coating protection. Before such instruments can be effectively utilized in the field, however, the specifications under which the paint system is being applied must state the minimum acceptable dry thickness for the completed coating. They should specify also the minimum number of coats for each paint used in the paint system. It should be made particularly clear that the thickness and continuity requirements govern the work, and that as many additional paint coatings shall be applied as are required to meet either the thickness requirements or the continuity requirements. With these general requirements in the specifications and with competent on-the-job inspection and field control, the quality of coating systems applied in the field should improve.

IMPELLER REPAIRS BY WELDING

By Leo Krapp

Superintendent of Sewage Disposal Maintenance, Cincinnati, Ohio

Recently the No. 5, 20-in. horizontal centrifugal raw sewage pump at the Little Miami Sewage Treatment Plant developed an unusual noise. This noise caused the pump to be shut down and opened for inspection. A large

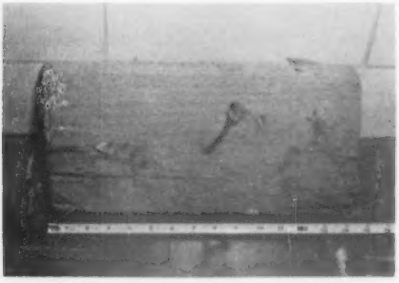


FIGURE 1.—Oak timber which broke impellers of two 20-in. pumps.

section of the cast iron impeller was found to be missing, but the cause of this damage was not determined immediately. Within a short time a similar noise was heard in the No. 4 raw sewage pump. This time inspection revealed that both flutes had been broken from the impeller, the pieces of which were still in the pump casing along with a 2- by 6- by 14-in. piece of oak timber (Figure 1). Apparently, the timber was the one that broke the No. 5 pump impeller and on shutting down had washed back into the wet well where it remained until it was drawn in by the No. 4 pump.

Procedure

After considering the possibility of having the pumps repaired by (*a*) an outside contractor, by (*b*) the purchase of new impellers, and by (*c*) welding, the latter was attempted.

On the No. 5 pump impeller the piece missing was about 4 in. wide and 12 in. long. This broken area was prepared in the usual manner of removing the oxides and beveling. An area approximately 10 in. from the break was preheated to 400°F to remove the chill from the casting as well as to relieve the built-up stresses. The first bead was then inlaid with

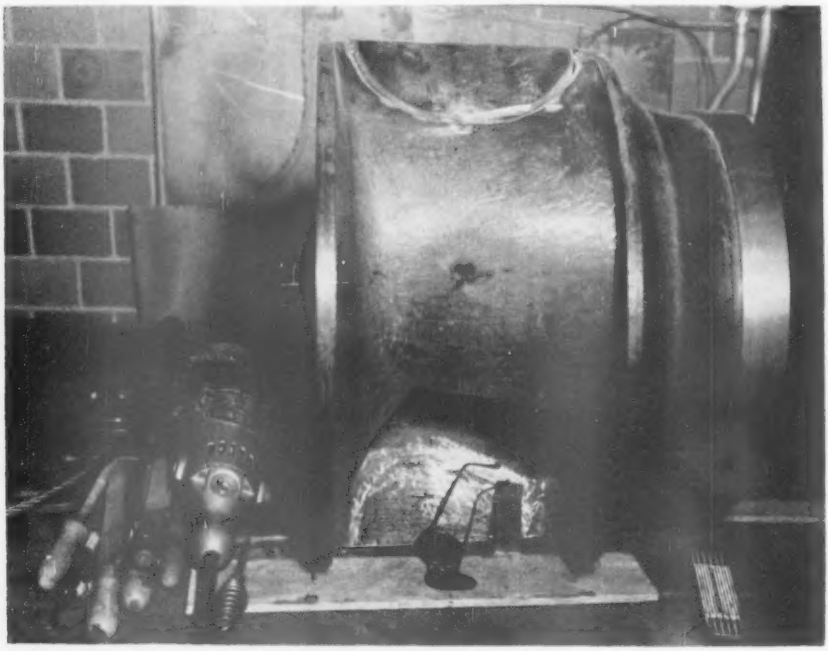


FIGURE 2.—Refitted impeller.

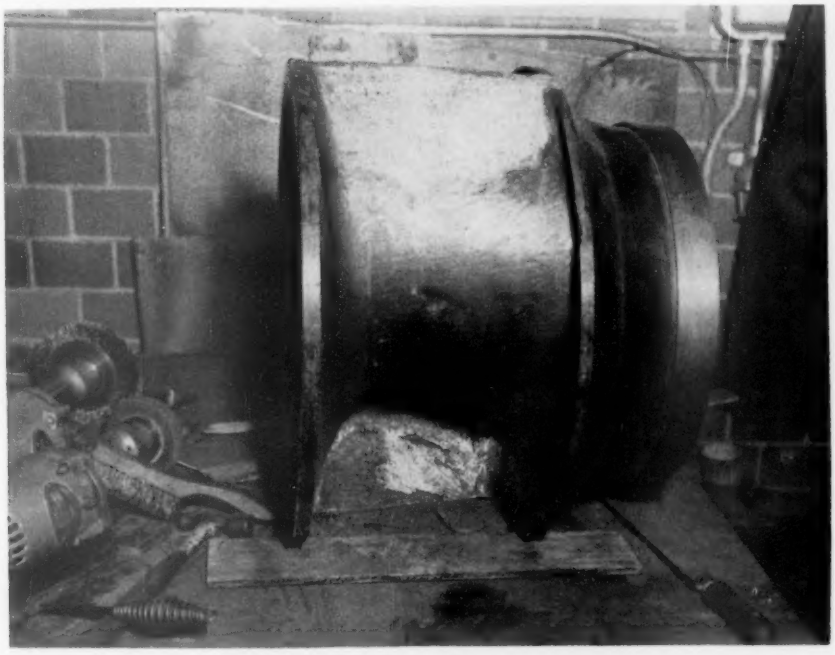


FIGURE 3.—Rewelded impeller.

Eutectic Eutectrode No. 27 at approximately 135 amp. This 3/32-in., tan tip, nickel-free electrode has an ultimate strength of 60,000 psi.

The slag was then chipped off and the weld wire brushed. The weld was then peened with a ball peen hammer to relieve any stresses in the casting around the welded area. Welding from this point utilized a Eutectic Xyron 2-25, light blue tip, ⅛-in. rod at 140 amp with reversed polarity. After each bead, the slag was chipped off and the weld wire brushed and peened.

The damaged section of the impeller was completely filled, in the manner described, following the contour of the casting. After completing the buildup, the area was ground to conform to the rest of the casting.

The impeller from pump No. 4, which had two sections broken out, was repaired in the same manner except that the pieces from the broken area were refitted and rewelded (Figures 2 and 3).

Vibration Check

Both impellers were reinstalled and then checked with a vibration analyzer while under load to see if the repairs had caused any unbalance. Tests indicated that the pumps were not affected by this repair.

Cost

The cost for making the repairs by this method was $225. This included the removal, repair, and resetting of both pumps. To date the pumps have operated in a perfectly satisfactory manner.

TIPS AND QUIPS

How's Your Frequency?

Everybody knows that most of the electric current supplied to cities in the U. S. has a frequency of 60 cycles per second. Sometimes the frequency varies though, and when it is more than 60, electric clocks gain time; when it is less than 60, clocks lose time.

At Cincinnati's Mill Creek Sewage Works, power is generated by gas-fired Diesel engines. To maintain the frequency at 60 cycles per second, this method is used:

A short-wave receiver is used to receive the correct time as broadcast by the National Bureau of Standards. The broadcast is monitored once a week, and after determining the correct time, a master pendulum clock is set. Next, the plant clocks are checked to determine the time difference. If the time difference is too great, adjustment of the engines must be made. So far, the difference has never exceeded 10 seconds.

Effect of Standing on Filtration Yields

At Cincinnati's Little Miami plant, Research Chemist Roy K. Snyder is usually busy determining the facts about a lot of things we speculate on.

One little study deals with the effect of time of standing on the filter yield of elutriated sludge treated with ferric chloride. The results are listed in Table I. A leaf filter and 26 in. of mercury were used to determine the yields. It can be seen that standing without agitation seems to be an unimportant factor in filtration yields.

Borough's Bore Holes Boring Board

Pennsylvania's Sanitary Water Board has had enough of the Borough of Kingston's bore holes. The Board has asked that an injunction be issued to restrain Kingston and the contractor from drilling bore holes in abandoned coal mines for the disposal of sewage.

Accidents in Indiana

The newsletter of the Indiana Sewage and Industrial Wastes Association reports on the results of safety questionnaires returned by 33 sewage treatment plants.

The report covered 328 workers who worked an estimated 544,000 hours. A total of 8 accidents was recorded with a loss of 432 man-days or 3,456 man-hours.

This rate of 14.6 accidents per million hours worked is much less than the national average of 39.7 for sanitation employees. Construction work, which is regarded as dangerous, has an average of 19.1 accidents per million hours worked.

MJ + SM = TM

If you're wondering what this means, wonder no further. It's the Metropolitan St. Louis Sewer District's way

TABLE I.—Sludge Filtration Yields of Various Sludges at Various Standing Times

Time (min)	Lebanon Sludge		Loveland Sludge		Digester 2 Sludge		Digester 3 Sludge	
	Solids (%)	Yield (psf/hr)	Solids (%)	Yield (psf/hr)	Solids (%)	Yield (psf/hr)	Solids (%)	Yield (psf/hr)
0	27.5	2.68	21.1	0.82	31.4	1.57	39.3	2.05
20	32.6	1.86	22.2	0.90	36.9	2.06	37.2	2.21
40	34.3	1.24	23.2	0.95	35.9	1.79	38.6	2.40
60	36.6	1.12	25.0	0.86	38.8	1.36	39.6	2.02

of saying that when you add their Manhole Jumper to Sewer Maintenance you come out with complete Traffic Maintenance.

The manhole jumper (see pictures) was designed by MSD's East Maintenance Division to protect new concrete which is placed after manholes are raised to new levels on repaved streets. Use is limited to major thoroughfares.

Manhole jumper being lowered into place.

Constructed of ½-in. steel plate, the jumpers are 60 in. in diam and weigh 580 lb, including the 196-lb manhole cover. Four 1½-in. lifting holes are drilled 90 deg apart. A 1-in. bolt is used to connect the steel plate to the manhole cover. The plate costs $70, and the cover, $19.

Jumper in place.

Rattling is prevented by using a small amount of hot asphalt to secure it to the street surface. The jumper is normally in place for a day or two before removal.

Incidentally, that East Maintenance Division, like the Salvation Army cornetist, is always there when needed. Plagued by an outbreak of inlet-cover thefts, East Maintenance came up with a concrete cover (see picture) that is perfectly adequate for pedestrian traffic. The stolen cast iron covers cost $12 apiece against $3.55 for the homemade kind.

Concrete inlet cover.

Cooling Towers

The general conclusion of Dow Chemical Company's 15-yr cooling tower study at Freeport, Tex., is "that non-oxidizing chemicals such as sodium pentachlorophenate or commercial formulations containing blended chlorophenates as the main ingredients are superior to all other methods tried in the past, including chlorine."

Editorial

PHILADELPHIA IN OCTOBER

For the 1960 meeting of your Federation, the dates are October 2–6 and the place is Philadelphia.

Soon after the Federation's meeting in 1958, the local Committees of the Host Association, the Pennsylvania Sewage and Industrial Wastes Association, started preparing for this event. Under the chairmanship of Mr. Samuel S. Baxter, Water Commissioner of the City of Philadelphia, these preparations have developed into planning for what promises to be a new high in Federation meeting quality.

The program will have 13 technical sessions with 50 papers, giving technical coverage more extended and more diversified than at any previous meeting. Manufacturers' exhibits will be arranged without restriction as to number because of the large area available in the Trade and Convention Center of Philadelphia. All technical sessions and exhibits will be in this Center.

Inspection trips will be offered to cater to those with interests in treatment in large and small municipal and industrial waste plants. The social program has been planned to take advantage of Philadelphia's ability to call on the finest offered.

In all, the role of the Local Arrangements Committee will be a full demonstration of what is meant by "Brotherly Love," for which our 1960 host city is justly famous. In fact, Convention attendants should not be surprised to see some committee members attired in clothing styled from Ben Franklin's era!

Wednesday, October 5, has been designated as "Industry Day," because special attractions have been provided in the technical program for those with an interest in industrial wastes. The technical program, arranged by the Federation Publications and Program Committee, under the chairmanship of Dr. George E. Symons, has had the cooperation of the Water Pollution Abatement Committee of the Manufacturing Chemists Association as well as the Federation Industrial Wastes Committee, of which Past-President Kenneth S. Watson is Chairman. As a result, the Philadelphia program will show exceptional strength in the technical sessions for those with industrial interests. The Industry Luncheon on this day will feature an industrial executive familiar with the problem. While Wednesday has been designated "Industry Day," the entire program will contain attractive items for industrial representatives.

For 1960 "Federation Week," you may expect the business sessions at your Board of Control on October 2 and October 6 to bracket a meeting glowing in all aspects. Come hear the technical papers and discussions. Come see the manufacturers' exhibits for the latest in equipment and processing. Come and enjoy the sparkling social program with its myriad of side lights culminating in the awards dinner and dance October 5. Above all, come see your fellow Federation members and a program supported not only by brotherly love but by the financial support of your host association as well as your 1960 host city.

It is time now to reserve these dates, to reserve your lodging space in Philadelphia, and to reserve your transportation accommodations to Philadelphia October 2–6, 1960.

R. E. F.

ANNUAL MEMBERSHIP CONTEST RULES

One of the most important constitutional objectives of the Federation is "the correlation and strengthening of regional and state sewage and industrial wastes associations or conferences." In partial fulfillment of this aim, the Board of Control has authorized an annual membership contest, rules for which follow:

1. All Member Associations of the Federation in good standing for the full year of each contest shall be eligible to compete. Formal application for entry is not required.

2. The term of the contest shall be the year ending September 30. All membership lists must be accompanied by check covering dues, and *must* be received at Federation headquarters before 5 PM on the closing day of the contest.

3. Two prizes will be awarded, as follows:

   a. One $100 cash award to the Member Association recording the greatest *percentage increase* in membership during the period of the contest.

   b. One $100 cash award to the Member Association recording the greatest *numerical increase* during the period of the contest.

4. At the termination of the contest on each September 30, the Executive Secretary of the Federation shall determine from his records the Member Associations having recorded the greatest numerical and percentage increases, and shall report his findings to the Board of Control at its next annual meeting. The Board of Control shall confirm the designation of the winning associations.

5. In the determination of membership, only those Active and Corporate Members receiving the publications of the Federation through the Member Association shall be credited to that Member Association, i.e., dual members will be credited only to the association through which they receive the Journal.

6. In the event that one Member Association shall record both the greatest *percentage* and the greatest *numerical* increase during the period of the contest, such association shall be eligible to receive only one of the prizes. The association recording the second greatest numerical increase during the contest shall be judged the winner of the other prize, in this case.

7. A winner of the percentage increase contest shall not be eligible to compete in this same contest within the next 5-yr period, unless its membership shall have reached a minimum of 25 Active and Corporate Members in the meantime.

8. In the event of a tie for either of the prizes, the total amount of the award shall be divided equally among the winning associations.

Reviews and Abstracts*

BOOKS, REPORTS, PAMPHLETS

Private Practice of Civil Engineering for the Use of Engineers and Clients. Professional Practice Committee of the American Society of Civil Engineers, New York. Manual 38. Price $1.00 (1959).

A replacement of ASCE's Manual 29 assembling more current information on the relationships between the engineer and clients. Heavy emphasis is placed on fees and charges.

Analysis of Pipe Structures for Flexibility. By JOHN GASCOYNE. John Wiley & Sons, Inc., New York. 181 pp. Price $7.50 (May 1959).

Recognizing the constantly changing needs in structural requirements for process piping, this British author covers in detail the various important aspects of the analysis of pipe structures for stress and flexibility. Subjects covered include: codes and standards, methods of stress calculation, preliminary data and basic assumptions, an elastic-center method of stress calculation, translation of results, pipe supports, and complete worked examples.

Air Pollution Control. By W. L. FAITH. John Wiley & Sons, New York. 259 pp. Price $8.50 (1959).

This book gives basic facts that must be considered in any air pollution control program, voluntary or mandatory. The presentation is aimed at a broad audience rather than to the air pollution specialist. The book includes an explanation of the effects of air pollution and the importance of meteorological variables, a discussion of the nature and source of the more common air pollutants, methods of determining the amounts of various contaminants in the air, the most appropriate means of controlling emissions at the source, legal means available for control, and the newer aspects of air pollution, particularly the automobile exhaust problem and the hazard of radioactivity.

Register of Dams in the United States. By T. W. MERMEL. McGraw-Hill, New York. 444 pp., 8½ × 11, 314 illustrations. Price $12.50 (1958).

This reference manual provides the essential statistics on over 2,800 important dams in the United States. For each dam, it gives the name, its location, structural data, ownership, by whom the engineering was performed, and who were the construction contractors.

The dams are alphabetically listed by name, and a cross reference of reservoir names (which may be different from the names of the dams) is provided. Pictures of over 300 dams are included.

In addition, the book presents a summary of laws of all 48 states dealing with the supervision and control of dams. Engineers or owners considering dam construction in any state will find concise information on what type of control is exercised by the state, as well as the name and address of the appropriate official and agency which exercises such control.

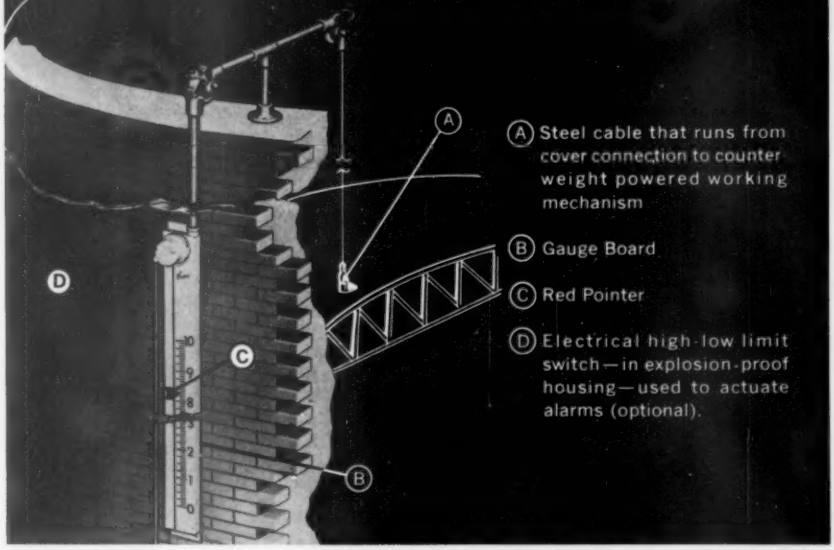
Water Pollution Research 1958. Department of Scientific and Industrial Research, London, England. 113 pp. Price 7/ (1959).

The report of the Water Pollution Research Board for 1958 with the Report of the Director of the Water Pollution Research Laboratory.

* Please send to Federation headquarters all periodicals, bulletins, special reports, etc., which might be suitable for abstracting in THIS JOURNAL. Publications of public health departments, stream pollution control agencies, research organizations, and educational institutions are particularly desired. Address such material: Water Pollution Control Federation, 4435 Wisconsin Ave., Washington 16, D. C.

VAREC INDICATOR

A SIMPLE, ACCURATE METHOD FOR INDICATING DIGESTER COVER POSITION


A
B
C
D
Ⓐ Steel cable that runs from cover connection to counter weight powered working mechanism
Ⓑ Gauge Board
Ⓒ Red Pointer
Ⓓ Electrical high-low limit switch—in explosion-proof housing—used to actuate alarms (optional).

Varec's economical gauge board indicator accurately gauges the movement of floating cover digesters with a simple working mechanism... displays readings on a 12-foot, easy-to-read anodized aluminum gauge board installed directly outside the digester.

The calibrated gauge board shows measurements in feet and inches... has a 10-foot range with an extra 2 feet of pointer measurement for greater cover or overflow travel. It provides 'quick-at-a-glance' reading with a bright red pointer that contrasts sharply against the white aluminum board and large, black numerals. All parts are ruggedly constructed and the working mechanism is enclosed in a protective housing.

VAREC OFFERS POSITION INDICATORS FOR ALL DIGESTER COVER NEEDS...

Other Varec cover position indicators include a dial type indicator that registers indication within a 10-foot range on a large, easily read dial and can be equipped with alarm switches. And, for remote control reading, Varec provides a highly-accurate gauge head indicator that delivers gauging accuracy to ½ inch... adapts for use with electrical or pneumatic remote reading or control equipment.

For complete information on all Varec digester cover position indicators, write for Varec Catalog No. S-4, Dept. JWP-1221-1

"Varec" TRADE ® MARK

THE VAPOR RECOVERY SYSTEMS COMPANY
2820 North Alameda Street • Compton, California
Branches and Representatives in Principal Cities

SYMBOLIC LOGIC

AEIOU ≠ (AWW = Z)

Take the phrase

"AMERICAN WELL WORKS OR EQUAL—"

Let AWW *stand for American Well Works*

Let Z *stand for all things equal to* AWW

Let the entire set of "vocal vowels" stand for what's not equal to AWW

Now, AWW *has the following attributes:*

- Experience rating of 92 years.
- Its sole business is engineering, design and manufacturing of equipment for sewage treatment, water purification, mixing and pumping. It has no outside activities.
- It owns extensive plant, equipment and manufacturing facilities all on one site to assure complete quality control.
- All of its products are unconditionally guaranteed as to function and performance.
- Its products are reasonably priced to enable owners and engineers to stay within estimates.
- It offers latest proved methods and designs.
- It has the highest available mercantile credit rating.
- It has the largest list of satisfied users in the United States.

THE PROBLEM:

Ignoring the entire set of "vocal vowels" (which are admittedly not equal to AWW*) solve for* Z *(what's equal to* AWW*)*

HINT FROM AWW *ENGINEERING DEPARTMENT:*

Even if Z *could easily be determined,*

Take AWW *for assured advantages*

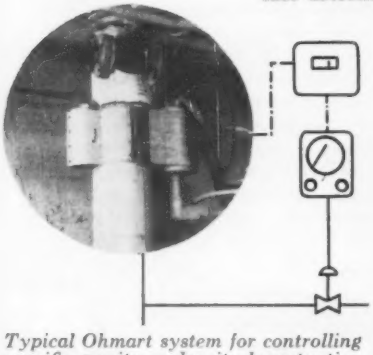
AMERICAN WELL WORKS AURORA, ILLINOIS

ohmart

ATOMIC "SENTINEL"

guarantees continuous, accurate, automatic density control!

Like a "sentinel" that never tires or sleeps, Ohmart Density Gages guard product quality, improve system efficiency, multiply your profits. Ohmart offers the most complete, standard line of nuclear gaging equipment for controlling the density variable in liquids or slurries, level measurement, and interface detection.



Typical Ohmart system for controlling specific gravity or density by actuation of a valve.

Ohmart Profit-Making Advantages:

- Each Ohmart installation carries a performance guarantee.
- Maintains single optimum point of density, automatically, by direct measurement.
- Quickly pays for itself through increased production and higher net profits; reduced variable and capital costs.
- Saves manpower, eliminates human error, cuts operating costs.
- System is ruggedly constructed, has no moving parts. Gages are not in contact with the media. There is nothing to clog, wear out, or corrode.
- Measures density to repeatabilities of 0.0005 specific gravity units or within 2% of selected range.

Atomic Operation:

Ohmart system employs a gamma radiation source with the patented Ohmart Cell as the detector which converts gamma radiation directly into electrical energy. Materials placed between the source and the cell absorb the energy in proportion to the density. As a result, cell output current is a measurement of the density. The output current is amplified and fed to any standard potentiometric recorder/controller. Departures from the optimum control point actuate controls necessary to bring the system back to optimum density. The gamma source is properly shielded for complete safety. Low radiation level cannot affect the materials measured.

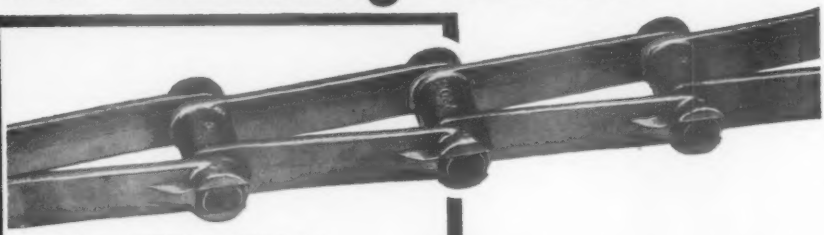
For full details, write for Bulletin 105-C.

ohmart

The Ohmart Corporation
2234 Bogen St., Cincinnati 22, Ohio

Engineering representatives in principal areas

Webster CHAIN for Handling Wastes

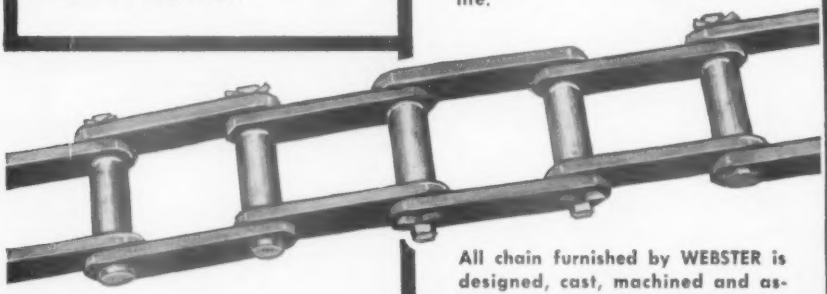


No. 720-S CHAIN

Designed especially for straight-line sludge and grit collectors, where long economical service is important. Pin and cotter construction. Pins have "T" heads securely fitted between lugs cast on side bars. This design prevents the pins from turning in the side bars, thereby distributing the wear over a large area in the barrels of the links. Available in malleable iron or Duramal which is approximately 20% stronger than malleable iron.

No. 111-N CHAIN

Designed for handling abrasive materials such as encountered in grit collectors. The barrels of the links are eliptical in shape to provide more material at point of greatest wear. This feature, together with the close-fitting joints, steel coupler links, and stationary steel pins provide maximum performance, sustained accuracy of pitch, and exceptionally long life.



All chain furnished by WEBSTER is designed, cast, machined and assembled in our Tiffin, Ohio plant.

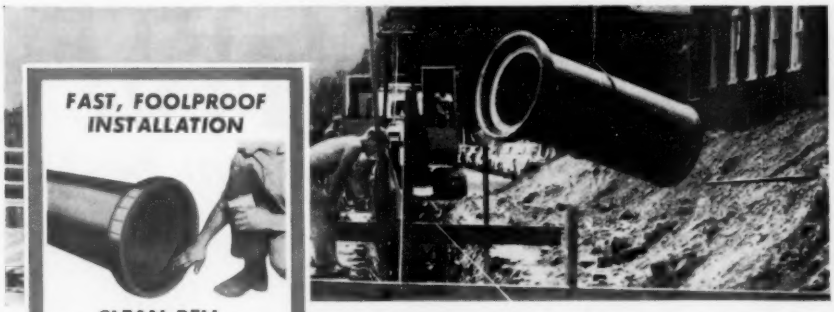
Webster MANUFACTURING, INC.

DEPT. SW-70, TIFFIN, OHIO

BULK MATERIALS HANDLING EQUIPMENT

SINCE W M 1876

Offices in all Principal Cities



FAST, FOOLPROOF INSTALLATION

CLEAN BELL

CLEAN SPIGOT

PLACE RUBBER "O" RING IN SPIGOT GROOVE

LINE UP, SHOVE INTO PLACE THAT'S ALL THERE IS TO IT!

TODAY'S

FAST, TIGHT, TOUGH FACTORY-MADE JOINT

Wedge-Lock* Type "O"

BY ROBINSON

Now Available In Diameters Through 36"

Now, lines go in faster, seal tighter, stay trouble-free longer. Robinson Type "O" joints reduce laying time . . . cut installation costs . . . are ideally suited to difficult installation conditions. New precision-tight Factory-Made Wedge-Lock Type "O" joints handle infiltration and roots in any terrain.

THE **ROBINSON** CLAY PRODUCT CO.
ESTABLISHED 1856
AKRON 9, OHIO

*Patented. T.M. Reg. U.S. Pat. Off.

FASTER SERVICE

You get quick delivery of all sizes from strategically located Robinson branches.

FOR MORE DETAILS

on Robinson Factory-Jointed Clay Pipe, Call the Robinson Branch Office nearest you.

AKRON 9, OHIO
65 W. State St. — POrtage 2-8601

ALBANY 4, N. Y.
1357 Broadway — HObart 3-4139

BALTIMORE 2, MD.
1546 Mathieson Bldg. — MUlberry 5-2930

BOSTON 34, MASS.
22 Pratt St., Allston Station — STadium 2-8900

BUFFALO 10, N. Y.
1146 Seneca St. — TRiangle 3082

CALDWELL TOWNSHIP, N. J.
Kulick Road (off Fairfield Road) — CApital 6-8800

CHICAGO 46, ILL.
7100 N. Lehigh Ave., Edgebrook Sta. — NEw Castle 1-5700

EAST HARTFORD 8, CONN.
170 Tolland St. — BUtler 9-4389

INDIANAPOLIS 7, IND.
1013-15 E. 21st St. — WAlnut 3-1507

NEW YORK, N. Y.
107-10 180th St., P. O. Box 589 Jamaica, L. I., N. Y. — REpublic 9-7100

PHILADELPHIA, PA.
P. O. Box 85, Pottstown, Pa. — FAculty 6-1310

ROCHESTER 11, N. Y.
609 Buffalo Road — BEverly 5-6990

SYRACUSE 3, N. Y.
534 Spencer St. — HArrison 2-9226

TORONTO, ONTARIO, CANADA
Baldwin Ave., Concord, Ontario, Canada — AVenue 5-1138

YONKERS, Westchester County, N. Y.
1013 Saw Mill River Road — YOnkers 8-7762

R-660 139

WHICH GRIT COLLECTOR *will protect your system best?*

LINK-BELT builds 7 types, can recommend the most efficient for your needs

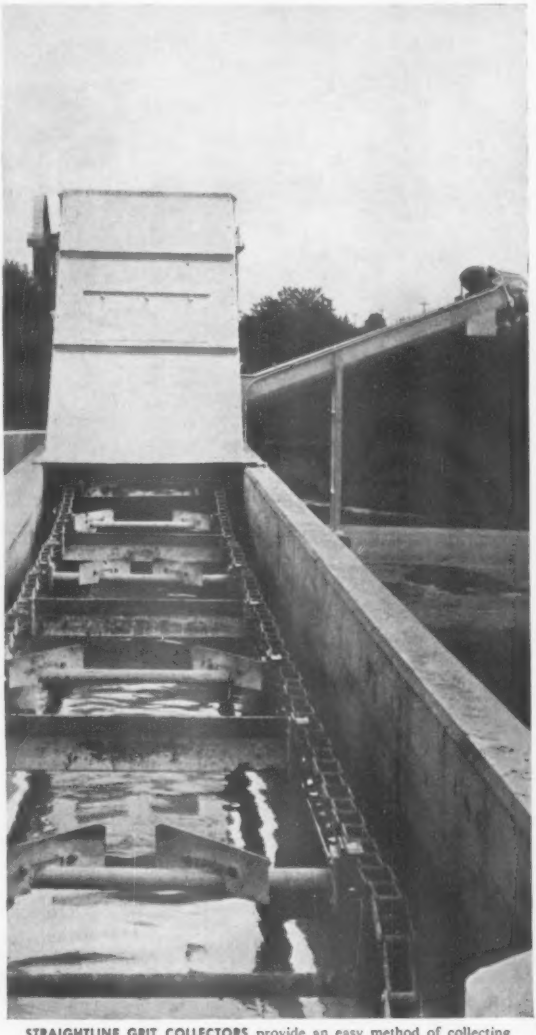
Modern sewage treatment requires grit removal to reduce maintenance costs on mechanical equipment and eliminate operational difficulties. Link-Belt has been manufacturing the finest in grit collection equipment for over 25 years—offers types and designs for any local conditions or requirements. For full details, contact your nearest Link-Belt office. Or write for your copy of Grit Collecting and Grit Washing Book 2571.

LINK-BELT

SANITARY ENGINEERING EQUIPMENT

TYPE AB AERATED GRIT COLLECTORS are ideal for large installations, or at plants where it is desirable to combine pre-aeration and grit removal in the same tank. They consist of a Type B grit collector and porous tubes for admitting compressed air.

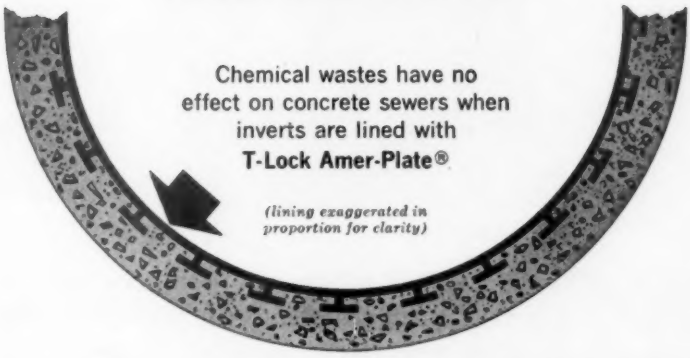
TYPE SW GRIT WASHER is a separate screw that washes and dewaters grit conveyed to it by pump, ejector, air lift or mechanical means. It can be counted on for long, dependable service in separating grit, water and putrescible matter.



STRAIGHTLINE GRIT COLLECTORS provide an easy method of collecting settled grit and inert solids without draining the grit chamber. These solids are dewatered and removed from the chamber by flight conveyors, screw conveyors, or buckets attached directly to the collectors. Shown is a Link-Belt Type B double-strand installation.

LINK-BELT COMPANY: Executive Offices, Prudential Plaza, Chicago 1. Sanitary Engineering Regional Offices—Colmar, Pa., Chicago 9, Kansas City 8, Mo., San Francisco 24. Sales Offices in All Principal Cities. Export Office, New York 7. Representatives Throughout the World. 15,008

How to Protect Concrete Sewers from Chemical Wastes


Chemical wastes have no effect on concrete sewers when inverts are lined with T-Lock Amer-Plate®
(lining exaggerated in proportion for clarity)

T-Lock Amer-Plate is a high polymer PVC sheet, easily cast into pipes, tunnels and structures to form a partial or complete 360° protective lining. Used in inverts, it permanently protects concrete from corrosive chemical effluents. In arch areas, it positively stops oxidized H_2S corrosion. T-Lock is also highly abrasion resistant; impartial tests show that it abrades at only 1/70th the rate of concrete.

The fact that T-Lock ends erosion and corrosion problems in industrial and municipal sewer systems is attested to by more than five million square feet now in use. Write for complete data on this maintenance-saving lining before designing your next sewer.

Applicators strategically located throughout U. S. and Canada

Amercoat® CORPORATION

Dept. SG • 4809 Firestone Boulevard • South Gate, California

921 Pitner Ave. Evanston, Ill. | 360 Carnegie Ave. Kenilworth, N.J. | 2404 Dennis St. Jacksonville, Fla. | 6530 Supply Row Houston, Texas | 111 Colgate Buffalo, N.Y.

110

KEY
to
37,000 JOURNAL Pages
in
Two Short Volumes

TWENTY-YEAR INDEX to *Sewage Works Journal*, 1928–1948, Volumes 1–20, provides complete indexing for these important 20 years, with 144 pages in handsome buckram binding, $3.00.

TEN-YEAR INDEX to *Sewage and Industrial Wastes*, 1949–1958, Volumes 21–30, covers 10-year period of the successor to original Journal; 168 pages; in buckram binding to match 20-Year Index, $4.00; in heavy paper, $3.00.

Both indexes contain separate listings by author, subject, and geographical categories, along with full cross-referencing. These features make them complete and easily used references.

Send orders to the Federation office; convenient coupon provided on WPCF Publications page elsewhere in JOURNAL.

WATER POLLUTION CONTROL FEDERATION

4435 Wisconsin Avenue Washington 16, D.C.

Twenty-foot lengths of Armco SMOOTH-FLO Pipe helped maintain uniform grade.

How Garden City, Kansas, installed a sewer in soupy soil

Water in the trench didn't stop installation of Armco Pipe.

Garden City, Kansas, recently installed a 1-mile interceptor sewer to feed their new treatment plant. Part of this line passed through extremely wet soil.

The contractor installed some 5,800 feet of Armco SMOOTH-FLO® Sewer Pipe in 20-foot lengths, with positive beam strength to maintain a continuous uniform grade in this unstable soil. SMOOTH-FLO's dense interior lining provided the necessary high flow capacity. An alternate material specification, for short-section pipe with nonpositive joints, called for expensive rigid bedding to maintain grade. The strong, lightweight Armco Pipe went in quickly and economically — with no special bedding required.

Get complete details on Armco Corrugated Metal Pipe. Write for catalog, "Armco Sewer Structures." Armco Drainage & Metal Products, Inc., 4350 Curtis Street, Middletown, Ohio.

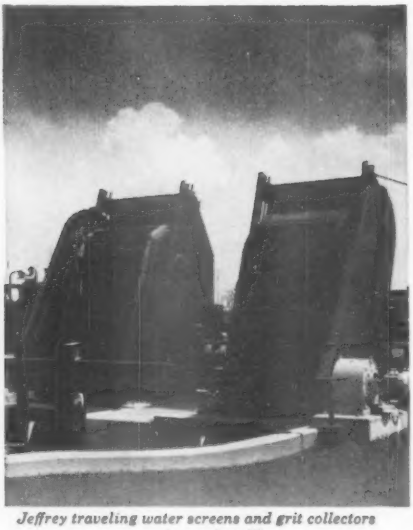
ARMCO DRAINAGE & METAL PRODUCTS

Subsidiary of ARMCO STEEL CORPORATION

OTHER SUBSIDIARIES AND DIVISIONS: Armco Division • Sheffield Division
The National Supply Company • The Armco International Corporation
Union Wire Rope Corporation

Water Clean-Up

...it's like finding a new source



Jeffrey traveling water screens and grit collectors in a pulp mill

Jeffrey water cleaning equipment can improve your plant operations and profits. Note these examples.

Jeffrey collectors at a steel mill

Jeffrey screens on water intake at a refinery

Use present source more effectively: In a pulp and paper mill, Jeffrey traveling screens reclaim 16,000 gallons of water per minute by removing tons of sand and bark. Production can be increased without having to seek a new water supply.

Reduce wear on plant machinery: In a steel mill, Jeffrey collectors remove metallic scale from process water, adding considerably to life of bearings. Also, downtime required for cleaning settling tanks was cut from 10 days to a day and a half.

Reclaim valuable materials: In many industries, Jeffrey screens and collectors are salvaging materials formerly carried away in process and wash water. Their recovery produces welcome additions to profits.

Jeffrey engineers will help analyze your waste problems and suggest means of recovery, disposal or neutralization. Bulletin 952 gives further information. For a copy, write Jeffrey Manufacturing Company, 902 North Fourth Street, Columbus 16, Ohio.

JEFFREY

CONVEYING • PROCESSING • MINING EQUIPMENT...TRANSMISSION MACHINERY...CONTRACT MANUFACTURING

Proceedings of Member Associations

PACIFIC NORTHWEST SEWAGE AND INDUSTRIAL WASTES ASSOCIATION

The 26th Annual Meeting of the Pacific Northwest Sewage and Industrial Wastes Association was held at the Tioga Hotel, Coos Bay, Ore., Oct. 29–30, 1959. Total registration for men was 245, second only to the Seattle meeting of 1957. Ladies registration set a new high of 67.

Two general sessions, two operators' sessions, an industrial wastes session, and a technical session were held. Subjects included: minimum design criteria, protective paint coatings, food products wastes problems, fiber board plant wastes, sewer infiltration, sludge composting, Zimmermann process, sewage stabilization ponds, disposal of radioactive wastes, various operators' problems, and several papers dealing with both liquid and atmospheric waste problems in the pulp and paper and metals industries. The operators held a closed round-table discussion, and the traditional operator's breakfast was held the next morning.

Dr. W. D. Hatfield, Past-President of the Federation, was the luncheon speaker. The Hatfield Award for outstanding plant operation was presented to Kenneth Mathews of Seattle, Wash., and the Bedell Award for extraordinary service went to Kenneth H. Spies of Portland, Ore. Awards for the best annual reports went to C. S. Zickefoose, Walla Walla, Wash. (cities over 25,000), Ted King, Springfield, Ore. (cities from 5,000 to 25,000), and Vern Young, Franklin-Pierce High

(*Continued on page 363a*)

specialists

★ Sewer and Pipe Cleaning Equipment

★ Sewer Rods ★ Sectional Steel Rods

★ Complete Sewer Cleaning Machines

★ Braces and Guides

★ Buckets, Root Cutters, Drag Tools

Save the cost of experimenting. Consult Stewart for any problem in the specialized field of pipe cleaning.

W.H.STEWART, INC. P.O. Box 767, Syracuse, N.Y.

WATER POLLUTION CONTROL PRODUCT GUIDE

This list of products and services is offered as an information aid. The list was derived by solicitation from those firms listed. The JOURNAL will make every effort to keep this list current with the help of members and advertisers. All Associate Members and all advertisers for the past year are included. Many of the services and products are advertised in this issue. For an alphabetical listing see Index to Advertisers in back of JOURNAL.

Aerators (*also see* Diffusers, Air)
Alpha Ltd. (Switzerland)
American Well Works
Chicago Pump Co.
Dorr-Oliver Inc.
Eimco Corp.
Graver Water Conditioning Co.
Infilco Inc.
Link-Belt Co.
Pacific Flush Tank Co.
Penberthy Mfg. Co., Div. of Buffalo-Eclipse Corp.
Permutit Co., Div. of Pfaudler Permutit Inc.
Smith & Loveless
Walker Process Equipment Inc.
Wemco Div., Western Machinery Co.
Yeomans Brothers Co.
Zimmer & Francescon

Agitators
Link-Belt Co.

Air Cleaning Equipment
Westinghouse Electric Corp.

Air Compressors (*also see* Blowers, Compressors, and Fans)
Chicago Pump Co.
Fairbanks, Morse & Co.
Komline-Sanderson Engr. Corp.
Worthington Corp.
Yeomans Brothers Co.

Air Diffusers (*see* Diffusers, Air)

Asbestos Cement Pipe Products
Filtration Equipment Corp.
Industrial Materials Co.
Johns-Manville Sales Corp.
Keasbey & Mattison Co.

Ash Handling Equipment
Link-Belt Co.

Automobiles and Trucks
Vulcan Materials Co.

Bearings
Link-Belt Co.

Bins, Storage (*see* Tanks)

Biologists (*see* Directory of Engineers)

Blowers (*also see* Air Compressors, Compressors, and Fans)
Chicago Pump Co.
Roots-Connersville Blower, Div. of Dresser Industries Inc.
Sutorbilt Corp.
Yeomans Brothers Co.
Zimmer & Francescon

Boilers
Combustion Engineering, Inc.

Building Maintenance Equipment and Supplies
Homestead Valve Mfg. Co.

Cast Iron Pipe Products
American Cast Iron Pipe Co.
Cast Iron Pipe Research Assn.
Industrial Materials Co.
U. S. Pipe & Foundry Co.
R. D. Wood Co.

Cement (*see* Concrete)

Centrifuging Equipment
Bird Machine Co.

Chains
Chain Belt Co.
Link-Belt Co.
Webster Mfg., Inc.

Chemical Feed Equipment
Builders-Providence Div., B-I-F Industries
Eimco Corp.
Fischer & Porter Co.
Graver Water Conditioning Co.
Infilco Inc.
Jeffrey Mfg. Co.
Komline-Sanderson Engr. Corp.
Link-Belt Co.
Omega Div., B-I-F Industries
Permutit Co., Div. of Pfaudler Permutit Inc.
Proportioneers Div., B-I-F Industries
Wallace & Tiernan Inc.

Chemicals
Dow Chemical Co.
Fisher Scientific Co.
General Chemical Div., Allied Chemical Corp.
Glenn Chemical Co.
Tennessee Corp.
Vulcan Materials Co.

Chemists (*see* Directory of Engineers)

Chlorination Equipment
Builders-Providence Div., B-I-F Industries
Everson Mfg. Co.
Fischer & Porter Co.
Graver Water Conditioning Co.
Wallace & Tiernan Inc.
Zimmer & Francescon

Clarifier Equipment (*also see* Sedimentation Equipment)
Alpha Ltd. (Switzerland)
American Well Works
Ralph B. Carter Co.
Chain Belt Co.
Chicago Pump Co.
Dorr-Oliver Inc.
Eimco Corp.
Graver Water Conditioning Co.
Hardinge Co., Inc.
Infilco Inc.
Jeffrey Mfg. Co.
Komline-Sanderson Engr. Corp.
Lakeside Engineering Corp.
Link-Belt Co.
Permutit Co., Div. of Pfaudler Permutit Co.
Walker Process Equipment Inc.
Yeomans Brothers Co.
Zimmer & Francescon

Clay Pipe Products
Industrial Materials Co.
National Clay Pipe Mfrs., Inc.
Robinson Clay Product Co.
Wedge-Lock Clay Pipe Mfrs., Inc.

Coatings and Linings (Pipe and Tank)
Amercoat Corp.
Centriline Corp.
Corrosion Control Co., Inc.
Inertol Co., Inc.
Koppers Co., Inc.
National Water Main Cleaning Co.
Perry-Austen Mfg. Co.
Stebbins Engr. & Mfg. Co.
Vulcan Materials Co.

Comminutors (*also see* Shredders and Grinders)
Alpha Ltd. (Switzerland)
American Well Works
Chicago Pump Co.
Dorr-Oliver Inc.
Gruendler Crusher & Pulverizer Co.
Infilco Inc.
Jeffrey Mfg. Co.
Smith & Loveless
Walker Process Equipment Inc.
Worthington Corp.

Compressors
Chicago Pump Co.
Fairbanks, Morse & Co.
Komline-Sanderson Engr. Corp.
Roots-Connersville Blower, Div. of Dresser Industries Inc.
Worthington Corp.
Yeomans Brothers Co.

Computers
Minneapolis-Honeywell Regulator Co., Brown Instruments Div.

Concentrators (*see* Sludge Concentrators)

Concrete
Portland Cement Assn.
Vulcan Materials Co.

Concrete Pipe Products
American Concrete Pressure Pipe Assn.
American-Marietta Co.
Gray Concrete Pipe Co., Inc.
Industrial Materials Co.
Lock Joint Pipe Co.
Portland Cement Assn.
Price Bros. Co.
Vulcan Materials Co.

Construction Equipment
Chain Belt Co.
Eimco Corp.
Worthington Corp.

WPCF publications

Safety in Wastewater Works

Contains information on hazards, accident statistics, rescue methods, safe practices, and equipment. *56 pages. $0.75 to members; $1.50 to others. Order as Item MOP-1.**

Utilization of Sewage Sludge as Fertilizer

An authoritative evaluation of advantages and limitations of sludge as a soil conditioner. *120 pages. $0.75 to members; $1.50 to others. Order as Item MOP-2.**

Chlorination of Sewage and Industrial Wastes

Reviews history, development, and up-to-date technique of chlorine application. *90 pages. $1.00 to members; $1.25 to others. Order as MOP-4.**

Air Diffusion in Sewage Works

History and modern practice in design, installation, operation, and maintenance of diffuser systems and appurtenances. *75 pages. $1.00 to members; $1.25 to others. Order as Item MOP-5.**

Units of Expression for Wastes and Waste Treatment

Lists of recommended units for quantities ordinarily encountered in wastes and waste treatment. *8 pages. $0.25 to members; $0.50 to others. Order as Item MOP-6.**

Sewer Maintenance

A guide for maintaining a municipal or industrial drainage system in serviceable condition. *64 pages. $1.00 to members; $1.50 to others. Order as Item MOP-7.**

Sewage Treatment Plant Design

Prepared jointly by the Federation and ASCE. Detailed presentation of the subject. *375 pages. $3.50 to members; $7.00 to others. Order as Item MOP-8.**

Design and Construction of Sanitary and Storm Sewers

Prepared jointly by the Federation and ASCE. Detailed presentation of the subject. *283 pages. $3.50 to members; $7.00 to others. Order as Item MOP-9.**

Twenty-Year Index to *Sewage Works Journal*

Covers *Sewage Works Journal*, 1928-1948. Author, subject, and geographic. *144 pages. Buckram bound, $3.00. Order as Item Dex-20.*

Ten-Year Index to *Sewage and Industrial Wastes*

Covers *Sewage and Industrial Wastes*, 1949-1958. Author, subject, and geographic. *168 pages. Buckram, $4.00; heavy paper, $3.00. Order as Item Dex-10.*

Glossary—Water and Sewage Control Engineering

Prepared jointly by the Federation, ASCE, AWWA, and APHA. 2,600 terms pertaining to nomenclature. *274 pages. $1.00. Order as Item Gl.*

Binder

Multiple wire, 2-in. capacity, for all MOP's listed except 8 and 9. *$2.00. Order as Item Bi.**

*** Discount of 15% on orders for 12 or more of any one manual.**

Water Pollution Control Federation
4435 Wisconsin Avenue, Washington 16, D. C.

Item	Copies	Cost	Item	Copies	Cost	Item	Copies	Cost
MOP-1			MOP-6			Bi		
MOP-2			MOP-7			Dex-20		
MOP-4			MOP-8			Dex-10		
MOP-5			MOP-9			Gl		

Enclosed is remittance for $ .....

Print Name .....

Address .....

City ..... Zone ..... State .....

Member Association .....

If an invoice is necessary, postage will be added. Checks may be made payable to WPCF.

Controls (*also see* Instruments, Recording and Control)
Builders-Providence Div., B-I-F Industries
Burgess-Manning Co., Penn Instruments Div.
Chicago Pump Co.
Fischer & Porter Co.
Foxboro Co.
General Electric Co.
Homestead Valve & Meter Co.
Infilco Inc.
Minneapolis-Honeywell Regulator Co., Brown Instruments Div.
Ohmart Corp.
Permutit Co., Div. of Pfaudler Permutit Co. Inc.
Rockwell Mfg. Co.
Wallace & Tiernan Inc.
Westinghouse Electric Corp.
Worthington Corp.

Conveyors
American Well Works
Chain Belt Co.
Chicago Pump Co.
Jeffrey Mfg. Co.
Link-Belt Co.
Webster Mfg., Inc.

Corrosion Protection
Amercoat Corp.
Chicago Pump Co.
Corrosion Control Co., Inc.
Inertol Co., Inc.
Johns-Manville Sales Corp.
Koppers Co., Inc.
Perry-Austen Mfg. Co.
Stebbins Engr. & Mfg. Co.
Wallace & Tiernan Inc.

Couplings
Link-Belt Co.

Diffusers, Air (*also see* Aerators)
Alpha Ltd. (Switzerland)
American Well Works
Carborundum Co.
Chicago Pump Co.
Dorr-Oliver Inc.
Eimco Corp.
Infilco Inc.
Lakeside Engineering Corp.
Link-Belt Co.
Pacific Flush Tank Co.
Penberthy Mfg. Co., Div. of Buffalo-Eclipse Corp.
Walker Process Equipment Inc.
Wemco Div., Western Machinery Co.
Zimmer & Francescon

Diffusers, Gas (*also see* Aerators)
American Well Works
Carborundum Co.
Chicago Pump Co.
Eimco Corp.
Infilco Inc.
Walker Process Equipment Inc.
Yeomans Brothers Co.

Digestion Tank Equipment
Alpha Ltd. (Switzerland)
American Well Works
Ralph B. Carter Co.
Chicago Pump Co.
Dorr-Oliver Inc.
Eimco Corp.
Gorman-Rupp Co.
Hardinge Co., Inc.
Infilco Inc.
Jeffrey Mfg. Co.
Lakeside Engineering Corp.
Link-Belt Co.
Pacific Flush Tank Co.
Smith & Loveless
Vapor Recovery Systems Co.
Walker Process Equipment Inc.
Yeomans Brothers Co.
Zimmer & Francescon

Distributors, Rotary
Alpha Ltd. (Switzerland)
American Well Works
Ralph B. Carter Co.
Dorr-Oliver Inc.
Eimco Corp.
Infilco Inc.
Lakeside Engineering Corp.
Link-Belt Co.
Pacific Flush Tank Co.
Smith & Loveless
Walker Process Equipment Inc.
Yeomans Brothers Co.
Zimmer & Francescon

Dryers
Alpha Ltd. (Switzerland)
Combustion Engineering, Inc.
Eimco Corp.
Hardinge Co., Inc.
Komline-Sanderson Engr. Corp.
Link-Belt Co.
Nichols Engr. & Research Corp.

Ejectors
Komline-Sanderson Engr. Corp.
Smith & Loveless
Tex-Vit Supply Co.
Yeomans Brothers Co.

Engineers (*see* Directory of Engineers)

Engines (Sludge Gas and Petroleum Fuels)
Climax Engine Mfg. Co.
Fairbanks, Morse & Co.
Waukesha Motor Co.
Worthington Corp.

Fans (*also see* Air Compressors, Blowers, and Compressors)
Chicago Pump Co.
Lakeside Engineering Corp.
Westinghouse Electric Corp.

Filter Equipment, Trickling
Alpha Ltd. (Switzerland)
American Well Works
Ralph B. Carter Co.
Dorr-Oliver Inc.
Dow Chemical Co.
Eimco Corp.
Filtration Equipment Corp.
Industrial Materials Co.
Infilco Inc.
Keasbey & Mattison Co.
Komline-Sanderson Engr. Corp.
Lakeside Engineering Corp.
Nichols Engr. & Research Corp.
Pacific Flush Tank Co.
Smith & Loveless
Trickling Filter Floor Inst.
Walker Process Equipment Inc.
Yeomans Brothers Co.
Zimmer & Francescon

Filter Materials
Carborundum Co.
Filtration Equipment Corp.
Glenn Chemical Co.
Graver Water Conditioning Co.
Industrial Materials Co.
Johns-Manville Sales Corp.
Vulcan Materials Co.

Filters, Diatomaceous Earth
Graver Water Conditioning Co.
Yeomans Brothers Co.

Filters, Vacuum (*also see* Vacuum Filters)
Bird Machine Co.
Dorr-Oliver Inc.
Eimco Corp.
Proportioneers Div., B-I-F Industries

Flocculating Equipment
Alpha Ltd. (Switzerland)
American Well Works
Ralph B. Carter Co.
Chain Belt Co.
Dorr-Oliver Inc.
Eimco Corp.
Graver Water Conditioning Co.
Hardinge Co., Inc.
Infilco Inc.
Jeffrey Mfg. Co.
Lakeside Engineering Corp.
Link-Belt Co.
Walker Process Equipment Inc.
Webster Mfg., Inc.
Zimmer & Francescon

Flotation Equipment
Chain Belt Co.
Dorr-Oliver Inc.
Eimco Corp.
Graver Water Conditioning Co.
Komline-Sanderson Engr. Corp.
Yeomans Brothers Co.

Flow Measurement
Burgess-Manning Co., Penn Instruments Div.
Filtration Equipment Corp.

Gas Control Equipment
Alpha Ltd. (Switzerland)
Burgess-Manning Co., Penn Instruments Div.
Ralph B. Carter Co.
Chicago Pump Co.
Dorr-Oliver Inc.
Eimco Corp.
Foxboro Co.
Homestead Valve Mfg. Co.
Pacific Flush Tank Co.
Rockwell Mfg. Co.
Vapor Recovery Systems Co.
Walker Process Equipment Inc.
Zimmer & Francescon

Gas Diffusers (*see* Diffusers, Gas)

Gas Holders, Boilers, and Appurtenances
Ralph B. Carter Co.
Chicago Pump Co.
Dorr-Oliver Inc.
Eimco Corp.
Johns-Manville Sales Corp.
Pittsburgh-Des Moines Steel Co.
Walker Process Equipment Inc.

Gaskets
Johns-Manville Sales Corp.
Keasbey & Mattison Co.

Gates
Armco Drainage & Metal Products, Inc.
Filtration Equipment Corp.
Industrial Materials Co.
Snow Gates & Valves, Inc.
Webster Mfg., Inc.

Generators
Climax Engine Mfg. Co.
Fairbanks, Morse & Co.
General Electric Co.
Westinghouse Electric Corp.
Worthington Corp.

Grinders (*also see* Shredders and Grinders)
Alpha Ltd. (Switzerland)
American Well Works
Chain Belt Co.
Dorr-Oliver Inc.
Gruendler Crusher & Pulverizer Co.
Jeffrey Mfg. Co.
Yeomans Brothers Co.

Grit Collection and Conditioning Equipment
Alpha Ltd. (Switzerland)
American Well Works
Chain Belt Co.
Chicago Pump Co.
Dorr-Oliver Inc.
Eimco Corp.
Infilco Inc.
Jeffrey Mfg. Co.
Link-Belt Co.
Walker Process Equipment Inc.
Webster Mfg., Inc.
Zimmer & Francescon

School, near Tacoma, Wash. (under 5,000). These awards include a certificate and a $25 bond.

A proposal to change the name of the association was submitted to a letter ballot in the form of a constitutional amendment. The name Pacific Northwest Pollution Control Association was adopted, effective Jan. 1, 1960.

Officers elected for 1960:

President: Robert O. Sylvester, Seattle, Wash.
Vice-President: Ray S. Fish, Medford, Ore.
Director: R. Trumbull Smith, Seattle, Wash.
Secretary-Treasurer: Gilbert H. Dunstan, Pullman, Wash.

G. H. DUNSTAN
Secretary-Treasurer

NEW YORK SEWAGE AND INDUSTRIAL WASTES ASSOCIATION

The 32nd Annual Meeting of the New York Sewage and Industrial Wastes Association was held at the Park Sheraton Hotel in New York City on Jan. 21 and 22, 1960. A total of 315 members and guests were registered.

At the first technical session the following papers were given: "New York State Oxidation Pond," by S. W. Williams of O'Brien and Gere, Syracuse; "Treatment Studies on Long Island Duck Farm Wastes," by Associate Professor C. D. Gates, Syracuse University; "Waste Treatment at the Poughkeepsie Plant of the International Business Machine Corp.," by Associate Plant Engineer J. J. Jefferson, IBM, Poughkeepsie; and "Chlorine Demands and Chlorine Requirements of an Industrial Waste," by M. C. Rand, Chief Chemist, Middlesex County Sewerage Authority, New Jersey, and J. V. Hunter, Lecturer in Sanitation, Rutgers University. A

(*Continued on page 365a*)

KILLS
PSYCHODA FLIES
in trickling filters

kills flies, larvae and pupae

without damage to zoogleal film

without destroying beneficial bacteria

without reducing filter efficiency

NEW INHIBITORY FACTOR—Hundreds of tests have demonstrated that R.S.C. is extremely effective in killing Psychodae which have shown high degree of resistance to DDT, Methoxychlor, Lindane, Chlordane, Dieldrin, Aldrin, Malathion and other insecticides.

This is accomplished by an inhibitory factor which renders a hitherto resistant fly susceptible to the insecticides in the R.S.C. formula. Field tests in such widely separated areas as Illinois, Texas, Florida have shown that use of R.S.C. reduces filter fly population to practically nil.

SAFE, ECONOMICAL—R.S.C. is registered by the United States Department of Agriculture for control of Psychoda flies. When used according to directions, R.S.C. is safe, economical, and the most effective method of filter fly control to date.

Send for literature and field test reports.

T.M.
R S C
PAT. APPL. FOR
GLENN
CHEMICAL CO.
Industrial Chemicals Division
CHICAGO 14, ILLINOIS

Grounds Maintenance Equipment and Supplies
Homestead Valve Mfg. Co.

Heating Equipment for Digesters and Buildings
Alpha Ltd. (Switzerland)
Ralph B. Carter Co.
Chicago Pump Co.
Dorr-Oliver Inc.
Eimco Corp.
General Electric Co.
Infilco Inc.
Link-Belt Co.
Pacific Flush Tank Co.
Walker Process Equipment Inc.

Incinerators
Combustion Engineering, Inc.
Morse Boulger, Inc.
Nichols Engr. & Research Corp.
Pittsburgh-Des Moines Steel Co.
Walker Process Equipment Inc.

Insect Control
Glenn Chemical Co.
Leeco Chemical Co., Div. of Leeco Gas & Oil Co.

Inspection, Sewers
Centriline Corp.
National Water Main Cleaning Co.

Instruments, Recording and Control (*also see* Controls and Recorders)
Builders-Providence Div., B-I-F Industries
Burgess-Manning Co., Penn Instruments Div.
Fischer & Porter Co.
Fisher Scientific Co.
Foxboro Co.
General Electric Co.
Infilco Inc.
Minneapolis-Honeywell Regulator Co., Brown Instruments Div.
Ohmart Corp.
Rockwell Mfg. Co.
Wallace & Tiernan Inc.
Westinghouse Electric Corp.

Ion-Exchange Equipment
Permutit Co., Div. of Pfaudler Permutit Inc.

Jointing Materials
American Concrete Pressure Pipe Assn.
Gray Concrete Pipe Co., Inc.
Keasbey & Mattison Co.
National Clay Pipe Mfrs., Inc.
Perry-Austen Mfg. Co.
Robinson Clay Product Co.
Stebbins Engr. & Mfg. Co.
Wedge-Lock Clay Pipe Mfrs.

Joints, Mechanical
American Cast Iron Pipe Co.
Johns-Manville Sales Corp.
Robinson Clay Product Co.
Smith-Blair, Inc.
U. S. Pipe & Foundry Co.
Wedge-Lock Clay Pipe Mfrs.

Laboratory Equipment and Supplies
Filtration Equipment Corp.
Fisher Scientific Co.
General Chemical Div., Allied Chemical Corp.

Lift Stations
Davco Corp.
Smith & Loveless
Tex-Vit Supply Co.

Lighting Fixtures
Westinghouse Electric Corp.

Lubricants
Homestead Valve Mfg. Co.
Johns-Manville Sales Corp.

Lumber
Vulcan Materials Co.

Manhole and Inlet Castings
American-Marietta Co.
Vapor Recovery Systems Co.
Vulcan Materials Co.

Masonry Building Materials
American-Marietta Co.
Portland Cement Assn.
Price Bros. Co.
Vulcan Materials Co.

Meter Boxes
Johns-Manville Sales Corp.

Meters (Sewage, Sludge, Water, Air, and Gas)
Builders-Providence Div., B-I-F Industries
Burgess-Manning Co., Penn Instruments Div.
Ralph B. Carter Co.
Filtration Equipment Corp.
Foxboro Co.
Infilco Inc.
Minneapolis-Honeywell Regulator Co., Brown Instruments Div.
Rockwell Mfg. Co.
Roots-Connersville Blower, Div. of Dresser Industries Inc.
Simplex Valve and Meter Co.
Worthington Corp.

Mixing Devices
Alpha Ltd. (Switzerland)
American Well Works
Ralph B. Carter Co.
Chain Belt Co.
Dorr-Oliver Inc.
Eimco Corp.
Infilco Inc.
Jeffrey Mfg. Co.
Walker Process Equipment Inc.
Wemco Div., Western Machinery Co.

Motors
Chicago Pump Co.
Fairbanks, Morse & Co.
General Electric Co.
Link-Belt Co.
Westinghouse Electric Corp.
Worthington Corp.

Odor Control Materials
Airkem Inc.
Florasynth Laboratories, Inc.
Tennessee Corp.
Wallace & Tiernan Inc.

Odor Counteractants
Airkem Inc.

Package Treatment
Chain Belt Co.
Chicago Pump Co.
Dorr-Oliver Inc.
Infilco Inc.
Municipal Service Co.
Smith & Loveless
Yeomans Brothers Co.

Packing
Johns-Manville Sales Corp.
Keasbey & Mattison Co.

Paints and Protective Coatings
Amercoat Corp.
Inertol Co., Inc.
Koppers Co., Inc.
Perry-Austen Mfg. Co.
Smith & Loveless
Stebbins Engr. & Mfg. Co.

Pipe, Asbestos Cement
Industrial Materials Co.
Johns-Manville Sales Corp.
Keasbey & Mattison Co.

Pipe, Cast Iron
American Cast Iron Pipe Co.
Cast Iron Pipe Research Assn.
Industrial Materials Co.
U. S. Pipe & Foundry Co.
R. D. Wood Co.

Pipe, Clay
Industrial Materials Co.
National Clay Pipe Mfrs., Inc.
Robinson Clay Product Co.
Wedge-Lock Clay Pipe Mfrs.

Pipe Cleaning
Centriline Corp.
Flexible Inc.
Homestead Valve Mfg. Co.
National Water Main Cleaning Co.
W. H. Stewart, Inc.

Pipe Coatings and Linings
Amercoat Corp.
American Pipe & Construction Co.
Centriline Corp.
Koppers Co., Inc.
National Water Main Cleaning Co.
Perry-Austen Mfg. Co.
Stebbins Engr. & Mfg. Co.
Vulcan Materials Co.

Pipe, Concrete
American Concrete Pressure Pipe Assn.
American-Marietta Co.
American Pipe & Construction Co.
Gray Concrete Pipe Co., Inc.
Lock Joint Pipe Co.
Portland Cement Assn.
Price Bros. Co.
Vulcan Materials Co.

Pipe, Fiber
Sonoco Products Co.

Pipe Fittings
American Cast Iron Pipe Co.
Cast Iron Pipe Research Assn.
Keasbey & Mattison Co.
Price Bros. Co.
Robinson Clay Product Co.
Smith-Blair, Inc.
U. S. Pipe & Foundry Co.
Wedge-Lock Clay Pipe Mfrs.
R. D. Wood Co.

Pipe Jointing Materials (*see* Jointing Materials)

Pipe, Plastic
Amercoat Corp.
Evanite Plastic Co.

Pipe, Repairs
Centriline Corp.
Smith-Blair, Inc.

Pipe, Steel
American Pipe & Construction Co.
Armco Drainage & Metal Products, Inc.
Keasbey & Mattison Co.

Plastic Pipe Products
Amercoat Corp.
Evanite Plastic Co.
Keasbey & Mattison Co.

Publications
American City Magazine
Engineering News-Record
Public Works Magazine
Wastes Engineering
Water & Sewage Works
John Wiley & Sons, Inc.

Pump Controls
Builders-Providence Div., B-I-F Industries
Burgess-Manning Co., Penn Instruments Div.
Chicago Pump Co.
Fischer & Porter Co.
Foxboro Co.
General Electric Co.
Minneapolis-Honeywell Regulator Co., Brown Instruments Div.
Rockwell Mfg. Co.
Smith & Loveless
Tex-Vit Supply Co.
Westinghouse Electric Corp.
Worthington Corp.
Zimmer & Francescon

written discussion of the paper by H. C. Marks, Director of Research of Wallace and Tiernan Inc., was read by A. E. Griffin, Staff Consultant of the same organization.

At the luncheon session, 185 members and guests attended. Federation Executive Secretary Ralph Fuhrman briefly discussed some of the affairs of the Federation and on behalf of the Federation presented the Bedell Award to A. F. Dappert and the Hatfield Award to James M. Brown. Mr. Brown, then acting as Chairman of the Association's Memorial Awards Committee, presented the Association's Kenneth Allen and Charles Agar Awards. The first went to Professor William T. Ingram for his paper, "An Investigation of the Mechanics of Filtration," the second to Francis V. Padar for his paper, "Individual and Subdivision Sewage Disposal Problems in New York City." Vice-President Bernhardt presented the Past-President's Key and Certificate to President Steffensen on behalf of the Association.

At the first afternoon technical session, four papers and a film were presented. The papers included: "An Industrial Approach to Combined Treatment of Industrial Wastes and Domestic Sewage," by J. Floyd Byrd, Pollution Control Engineer of Procter and Gamble, Cincinnati, Ohio; "Levels of Detergents in Sewage Treatment Processes," by R. M. Manganelli, H. E. Orford, and C. N. Henderson of Rutgers University; "Sewer Inspection Using Photographic Methods," by V. L. Packard, Director of Public Utilities, Niagara Falls; and "Ten Years of Water Pollution Control Program in New York State," by A. F. Dappert, Executive Secretary, New York State Pollution Control Board. A film entitled "Lifetime Protection for Sewerage Structures," presented by T. W. Ward, Sales Engineer, Amercoat Corporation, dealt with vinyl

(*Continued on page 367a*)

SNOW GATES

for

SEWAGE TREATMENT PLANTS

All types of cast iron gates manufactured in either square or circular opening in sizes up to and including 72 inches.

ALL SNOW GATES and Lifts are "Parkerized" for protection against rust and corrosion.

Over 40 years continuous service to the industry.

We will be pleased to quote on any type of water controlling equipment.

SNOW GATES & VALVES

2437 East 24th Street Los Angeles 54, Calif.

Pumps, Airlift
Davco Corp.
Walker Process Equipment Inc.

Pumps, Chemical Feed
Proportioneers Div., B-I-F Industries

Pumps, Gas
Roots-Connersville Blower, Div. of Dresser Industries Inc.
Sutorbilt Corp.

Pumps, Grit
Nagle Pumps, Inc.

Pumps, Sewage
Alpha Ltd. (Switzerland)
American Well Works
Chicago Pump Co.
Davco Corp.
Eimco Corp.
Fairbanks, Morse & Co.
Gorman-Rupp Co.
Infilco Inc.
Marlow Pumps, Div. of Bell & Gossett Co.
Smith & Loveless
Sutorbilt Corp.
Wallace & Tiernan Inc.
Wemco Div., Western Machinery Co.
Worthington Corp.
Yeomans Brothers Co.
Zimmer & Francescon

Pumps, Sludge
Alpha Ltd. (Switzerland)
American Well Works
Ralph B. Carter Co.
Chicago Pump Co.
Dorr-Oliver Inc.
Eimco Corp.
Fairbanks, Morse & Co.
Gorman-Rupp Co.
Hardinge Co., Inc.
Infilco Inc.
Komline-Sanderson Engr. Corp.
Marlow Pumps, Div. of Bell & Gossett Co.
Nagle Pumps, Inc.
Sutorbilt Corp.
Wallace & Tiernan Inc.
Wemco Div., Western Machinery Co.
Worthington Corp.
Yeomans Brothers Co.
Zimmer & Francescon

Pumps, Vacuum
Roots-Connersville Blower, Div. of Dresser Industries Inc.
Sutorbilt Corp.

Pumps, Water
American Well Works
Ralph B. Carter Co.
Chain Belt Co.
Chicago Pump Co.
Eimco Corp.
Fairbanks, Morse & Co.
Gorman-Rupp Co.
Marlow Pumps, Div. of Bell & Gossett Co.
Wallace & Tiernan Inc.
Worthington Corp.
Yeomans Brothers Co.
Zimmer & Francescon

Radiation Monitoring Equipment
Westinghouse Electric Corp.

Radios, Mobile
General Electric Co.

Recorders (*also see* Instruments, Recording, and Control)
Builders-Providence Div., B-I-F Industries
Burgess-Manning Co., Penn Instruments Div.
Fischer & Porter Co.
Fisher Scientific Co.
Foxboro Co.
General Electric Co.
Minneapolis-Honeywell Regulator Co., Brown Instruments Div.
Ohmart Corp.
Wallace & Tiernan Inc.

Refractory Building Materials
Carborundum Co.
Johns-Manville Sales Corp.
Robinson Clay Product Co.
Stebbins Engr. & Mfg. Co.

Safety Equipment
Vapor Recovery Systems Co.

Sampling Equipment
Chicago Pump Co.
Infilco Inc.
Lakeside Engineering Corp.

Sand, Gravel, and Stone
Graver Water Conditioning Co.
Vulcan Materials Co.

Screening Equipment
Alpha Ltd. (Switzerland)
American Well Works
Chain Belt Co.
Chicago Pump Co.
Dorr-Oliver Inc.
Eimco Corp.
Infilco Inc.
Jeffrey Mfg. Co.
Link-Belt Co.
Walker Process Equipment Inc.
Zimmer & Francescon

Sedimentation Equipment (*also see* Clarifier Equipment)
Alpha Ltd. (Switzerland)
American Well Works
Ralph B. Carter Co.
Chain Belt Co.
Dorr-Oliver Inc.
Eimco Corp.
Graver Water Conditioning Co.
Hardinge Co., Inc.
Infilco Inc.
Jeffrey Mfg. Co.
Komline-Sanderson Engr. Corp.
Lakeside Engineering Corp.
Link-Belt Co.
Walker Process Equipment Inc.
Webster Mfg., Inc.
Yeomans Brothers Co.

Sewer Cleaning Equipment
Flexible Inc.
Homestead Valve Mfg. Co.
National Water Main Cleaning Co.
W. H. Stewart, Inc.

Sewer Inspection (*see* Inspection, Sewers)

Shredders (*also see* Comminutors and Grinders)
Alpha Ltd. (Switzerland)
Chain Belt Co.
Dorr-Oliver Inc.
Gruendler Crusher & Pulverizer Co.
Jeffrey Mfg. Co.
Yeomans Brothers Co.

Siphons
Alpha Ltd. (Switzerland)
American Well Works
Ralph B. Carter Co.
Eimco Corp.
Infilco Inc.
Lakeside Engineering Corp.
Pacific Flush Tank Co.
Yeomans Brothers Co.

Sludge Concentrators
Eimco Corp.
Nichols Engr. & Research Corp.

Sludge Flotation Equipment (*see* Flotation Equipment)

Sludge Handling and Control
Chain Belt Co.
Dorr-Oliver Inc.
Eimco Corp.
Jeffrey Mfg. Co.
Link-Belt Co.
Nichols Engr. & Research Corp.
Walker Process Equipment Inc.

Sludge Removal Equipment
Jeffrey Mfg. Co.
Link-Belt Co.
Webster Mfg., Inc.

Sludge Shredders
Alpha Ltd. (Switzerland)
Gruendler Crusher & Pulverizer Co.
Jeffrey Mfg. Co.

Sprockets
Chain Belt Co.
Link-Belt Co.
Webster Mfg., Inc.

Steel Pipe Products
Armco Drainage & Metal Products, Inc.

Structural Metal
Alpha Ltd. (Switzerland)

Switchgears
Alpha Ltd. (Switzerland)
General Electric Co.
Westinghouse Electric Corp.
Worthington Corp.

Tanks
Chain Belt Co.
Link-Belt Co.
Pittsburgh-Des Moines Steel Co.
Preload Co., Inc.
Stebbins Engr. & Mfg. Co.

Tools
Flexible Inc.

Transformers
Alpha Ltd. (Switzerland)
General Electric Co.
Westinghouse Electric Corp.

Trickling Filter Equipment (*see* Filter Equipment, Filter)

Trucks and Tractors
Eimco Corp.

Turbines
Worthington Corp.

Vacuum Filters (*also see* Filters, Vacuum)
Bird Machine Co.
Dorr-Oliver Inc.
Eimco Corp.
Komline-Sanderson Engr. Corp.
Proportioneers Div., B-I-F Industries

Valves and Gates
Armco Drainage & Metal Products, Inc.
Builders-Providence Div., B-I-F Industries
Chapman Valve Mfg. Co.
DeZurik Corp.
Filtration Equipment Corp.
Homestead Valve Mfg. Co.
Industrial Materials Co.
Iowa Valve Co.
Mueller Co.
Rockwell Mfg. Co.
Roots-Connersville Blower, Div. of Dresser Industries Inc.
Simplex Valve and Meter Co.
A. P. Smith Mfg. Co.
Snow Gates & Valves, Inc.
Westinghouse Electric Corp.
W-K-M Division, ACF Industries, Inc.
R. D. Wood Co.
Yeomans Brothers Co.

Vessels (*see* Tanks)

Weighing Devices
Builders-Providence Div., B-I-F Industries
Fairbanks, Morse & Co.
Fisher Scientific Co.
Wallace & Tiernan Inc.

AUTOMATIC LUBRICATION For Centrifugal Pump Glands

The Z-F Grease Seal applies constant positive lubrication to packing and shaft – automatically. Improved shut-off mechanism permits use of either grease or oil.

No more trouble spot where shaft enters casing – eliminates excessive heat, rapid wear, leakage and scoring.

Horizontal or vertical mounting. Many other advantages too. Write for complete description and price.

Zimmer & Francescon, P. O. Box 359, Moline, Ill.

ZF

chloride resin sheet linings applied to concrete structures exposed to sewage.

The second day's technical session included three papers: "Operation of Sewage Treatment Plants for the New York State Thruway Authority," by I. P. Sander, Senior Sanitary Engineer of the Authority; "Operating Experiences with Small Sewage Treatment Plants at Small Isolated Military Installations," by William Wechter, Sanitary Engineer, First Army Headquarters, New York; and "Operation of High Rate Digesters at the Jamaica Sewage Treatment Plant of New York City," by Norman Nash and A. H. Chasick, Engineers, New York City Department of Public Works.

The closing afternoon session was in charge of G. A. Fleet of the Program Committee. The three papers presented included: "Ion Concentration in Anaerobic Digestion," by P. L. McCarty and R. E. McKinney, Assistant and Associate Professors of Sanitary Engineering, Massachusetts Institute of Technology; "DeLaval Whey Protein Process," by Henry Wall, Vice President, Graoe Dairy, East Aurora, N. Y., and W. W. Pinckney, DeLaval Separator Company, Poughkeepsie; and "Experimental Treatment of Cottage Cheese Whey Bearing Wastes," by W. T. Ingram, Adjunct Professor, New York University.

At the business meeting, these officers were elected for the year 1960–61:

President: C. J. Bernhardt, Hamburg.
Vice-President: Guy Griffin, White Plains.
Director: R. C. Sweeney, White Plains.
Secretary: R. C. Sweeney, White Plains.
Treasurer: D. B. Stevens, Albany.

R. C. SWEENEY
Secretary

FOR SALE

Equipment from a complete primary-secondary activated sewage treatment plant employing separate sludge digestion and vacuum filtration built-in units. Design capacity 4.5 mgd. Good condition.

Bergen County Sewer Authority
Box 122
Little Ferry, New Jersey
HUbbard 7-1350

Equipment and Supply Lines

Sewage Testing Unit—Bulletin FS-242 of the Fisher Scientific Co., 717 Forbes St., Pittsburgh 19, Pa., describes, in detail, the Fisher-Hatfield Sewage Testing Unit. This packaged laboratory was developed jointly by Fisher and Past-President W. D. Hatfield. Units are available in four size categories: small plants (population under 7,500); large primary plants (over 7,500); medium-size secondary plants (7,500–25,000); and large secondary plants (over 25,000).

Adjustable Speed Drives—A new, low-cost line of eddy current coupling adjustable speed drives, with rating from 5 to 100 hp, has been announced by the General Electric Co., Schenectady 5, N. Y. The "Kinatrol" line is being offered as a complete package including the drive unit, control enclosure with control for both coupling and integrally mounted motor, and operator's station.

Vacuum Filters—A water-filled loop (Figure 1) is utilized in a cloth discharger licensed by Peterson Filters and Engineering Company, Salt Lake City, Utah. The discharger is said to fit any size drum filter.

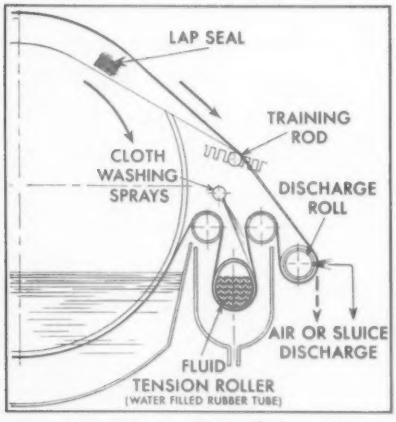


FIGURE 1.—Cloth discharger.

Paint Specifications—A 24-page booklet of the Perry-Austen Co., Inc., 250 Parkinson Ave., Staten Island 5, N. Y., contains information on: surface preparation, itemized specifications for surfaces and equipment in sewage treatment plants, complete specifications for sewage treatment plants, product information, and a color chart.

FIGURE 2.—Air comb.

Diffuser—A new "Aircomb" diffuser (Figure 2) with self-cleansing non-clog teeth has been announced. The diffuser is cast in bronze, aluminum, cast iron, or any other necessary material.—Bulletin 415, American Well Works, Aurora, Ill.

Sealed Electrode—The "Sealtrode" sealed electrode floatless pump controller is the topic of Bulletin 128A.—Chicago Pump Co., 622 Diversey Parkway, Chicago 14, Ill.

Compressed Air—"Compressed Air Fundamentals" is the title of a new booklet, Form 1548, published by Ingersoll-Rand, 11 Broadway, New York 4, N. Y. The bulletin describes compressed air, how it is compressed, single- and two-stage compressors, piston displacement, actual delivery, unloading of compressors, and regulation and types of control.

DIRECTORY OF ENGINEERS

ALBRIGHT & FRIEL, INC.
CONSULTING ENGINEERS

Water, Sewage, Industrial Wastes and Incineration Problems
City Planning, Highways, Bridges and Airports
Dams, Flood Control, Industrial Buildings
Investigations, Reports, Appraisals and Rates

THREE PENN CENTER PLAZA
PHILADELPHIA 2, PA.

ALVORD, BURDICK & HOWSON
Engineers
Charles B. Burdick Louis R. Howson
Donald H. Maxwell

Water Works, Water Purification, Flood Relief, Sewerage, Sewage Disposal, Drainage, Appraisals, Power Generation

Civic Opera Building Chicago

ANDERSON-NICHOLS & Company
Consulting Engineers
Water Supply, Distribution and Treatment, Industrial Waste Treatment, Sewage Collection and Disposal, Refuse Collection and Disposal, Drainage, Highways and Bridges.

Hartford, Conn. Boston 14

JOHN J. BAFFA
Consulting Engineer
Sewerage & Sewage Treatment
Industrial Wastes Treatment
Design Plans & Specifications
Investigations & Rate Studies

75 West Street New York 6, N. Y.

MICHAEL BAKER, JR., Inc.
Consulting Engineers
Civil Engineers, Planners, and Surveyors

Municipal Engineers—Airport Design—Sewage Disposal Systems—Water Works Design and Operation—Surveys and Maps—City Planning—Highway Design—Construction Surveys—Pipe Line Surveys

Home Office: Rochester, Pa.
Branch Offices: Jackson, Miss. Harrisburg, Pa.

BAXTER AND WOODMAN
Civil and Sanitary Engineers
Water Supplies Water Treatment
Sewer Systems Sewage Treatment
Industrial Waste Treatment
Investigations

P. O. Box 166 Crystal Lake, Illinois

THOMAS W. BEAK
Consulting Biologist
Pollution Studies
Stream and Lake Surveys
Toxicity Tests
Biological and Chemical Analyses

Amherst View, Collins Bay, Kingston, Ontario, Canada

HOWARD K. BELL
Consulting Engineers
G. S. Bell C. G. Gaither J. K. Latham
J. W. Finney, Jr.

Sewerage Water Works
Sewage Treatment Water Purification
Refuse Disposal Swimming Pools
Industrial Wastes

553 S. LIMESTONE ST., LEXINGTON, KY.

BETZ LABORATORIES, INC.
Consulting Engineers
Industrial Waste
Industrial Water
Analysis Design
Investigations Operation

Gillingham & Worth Sts. Philadelphia 24, Pa.

ONLY $75 PER YEAR
is the cost of a professional listing in this space. A card here will identify your firm with the specialized sewage and industrial wastes field and will afford maximum prestige!

It pays to secure competent and experienced engineering advice!

DIRECTORY OF ENGINEERS

BLACK & VEATCH
Consulting Engineers
Sewage – Gas – Water – Electricity – Industry
Reports, Design, Supervision of Construction, Investigations, Valuation and Rates
1500 Meadow Lake Parkway
Kansas City 14, Mo.

CLINTON BOGERT ENGINEERS
Consultants
CLINTON L. BOGERT — IVAN L. BOGERT
DONALD M. DITMARS — ROBERT A. LINCOLN
CHARLES A. MANGANARO — WILLIAM MARTIN
Water & Sewage Works — Incinerators
Drainage — Flood Control
Highways and Bridges — Airfields
145 East 32nd Street, New York 16, N. Y.

BOWE, ALBERTSON & ASSOCIATES
Engineers
Water and Sewage Works
Industrial Wastes
Refuse Disposal
Valuations
Laboratory Service
75 West St., New York 6, N.Y.
1000 Farmington Ave., West Hartford 7, Conn.

BOYLE ENGINEERING
Consulting Engineers
Water — Sewers — Streets
Structures — Surveys
Reports—Special Districts
331 Spurgeon Bldg., Santa Ana, Calif.
3913 Ohio, Rm. 200, San Diego 4, Calif.

CONSULTING ENGINEERS!
If you specialize in sewage and industrial waste disposal problems, prospective clients will expect to find your card in the Directory of Engineers contained in the . . .
Official Professional Journal of the Sewage and Industrial Wastes Field!

BROWN AND CALDWELL
CIVIL AND CHEMICAL ENGINEERS
WATER - SEWAGE - INDUSTRIAL WASTE
CONSULTATION - DESIGN - OPERATION
CHEMICAL AND BACTERIOLOGICAL LABORATORIES
66 MINT STREET SAN FRANCISCO 3

BROWN ENGINEERING CO.
Consulting Engineers
Water and Sewage Works
Industrial Waste Control and Treatment
Laboratory Services
508 TENTH STREET DES MOINES, IOWA

FLOYD G. BROWNE AND ASSOCIATES
F. G. Browne — S. W. Kuhner
W. G. Smiley — C. R. Martin
G. M. Hinkamp — W. H. Kuhn
Consulting Engineers
Water - Sewage - Industrial Wastes - Power
Reports, Designs, Construction Supervision, Investigations, Laboratory
123-125 W. Church Street Marion, Ohio

Your firm should be listed here
. . . the most complete Directory available of consultants specializing in sewage and industrial wastes treatment.

BUCK, SEIFERT AND JOST
Consulting Engineers
Specializing in Sewerage and Sewage Disposal, Water Supply and Water Purification, Valuations and Reports
Chemical and Biological Laboratories
112 East 19th Street New York 3, N. Y.

JOURNAL
Advertising Pages
These pages provide assistance to you when service is needed in the wastewater field. The WPCF Product Guide, in the final pages of the JOURNAL, also assist the readers.

Take advantage of the services of these outstanding consultants!

BURGESS & NIPLE
Civil and Sanitary Engineers
Established 1908
Sewage and industrial wastes disposal
Investigations, reports, design, rates
Laboratories, Plant Supervision
2015 W. Fifth Ave. Columbus 12, Ohio

DIRECTORY OF ENGINEERS

BURNS & McDONNELL
Engineers - Architects - Consultants
4600 E. 63rd St. Trafficway
Kansas City 41, Missouri

CAMP, DRESSER and McKEE
Consulting Engineers
Water Works and Water Treatment
Sewerage and Sewage Treatment
Municipal and Industrial Wastes
Investigations and Reports
Design and Supervision
Research and Development
Flood Control
18 Tremont Street Boston 8, Mass.

Your firm should be listed here
. . . the most complete Directory available of consultants specializing in sewage and industrial wastes treatment.

CAPITOL ENGINEERING CORPORATION
Engineers—Constructors—Management
SEWAGE SYSTEMS — Designs and Surveys, Planning, Bridges
WATER WORKS — Roads and Streets, Airports, Dams
Executive Offices
DILLSBURG, PENNSYLVANIA

THE CHESTER ENGINEERS
Water Supply and Purification
Sewage Treatment
Industrial Waste Disposal and Recovery
Power Plants–Incineration–Gas Systems
Valuations–Rates–Management
Laboratory
601 Suismon St., Pittsburgh 12, Penna.

CONSULTING ENGINEERS!
If you specialize in sewage and industrial waste disposal problems, prospective clients will expect to find your card in the Directory of Engineers contained in the . . .
Official Professional Journal of the Sewage and Industrial Wastes Field!

ONLY $75 PER YEAR
is the cost of a professional listing in this space. A card here will identify your firm with the specialized sewage and industrial wastes field and will afford maximum prestige!

CONSOER, TOWNSEND & ASSOCIATES
Water Supply—Sewerage—Flood Control & Drainage—Bridges—Ornamental Street Lighting—Paving—Light and Power Plants. Appraisals.
360 East Grand Ave. Chicago 11, Ill.

JOURNAL
Advertising Pages
These pages provide assistance to you when service is needed in the wastewater field. The WPCF Product Guide, in the final pages of the JOURNAL, also assist the readers.

ROY B. EVERSON Sanitary and Hydraulic Engineer
Sewage and industrial wastes treatment, city water purification, and complete swimming pool systems—Filtration Experience since 1900
Valuations—Reports—Research—Development
207 W. Huron St., Chicago 10, Ill.
SUperior 7-3339

It pays to secure competent and experienced engineering advice!

DIRECTORY OF ENGINEERS

JOURNAL
Advertising Pages

These pages provide assistance to you when service is needed in the wastewater field. The WPCF Product Guide, in the final pages of the JOURNAL, also assist the readers.

FAY, SPOFFORD & THORNDIKE, INC.
ENGINEERS
Sewage Treatment—Sewerage and Drainage Systems
Water Supply and Distribution—Incinerators
Airports—Bridges—Express Highways—Port and Terminal Works—Industrial Buildings
11 Beacon Street **Boston 8, Massachusetts**

ONLY $75 PER YEAR
is the cost of a professional listing in this space. A card here will identify your firm with the specialized sewage and industrial wastes field and will afford maximum prestige!

FINKBEINER, PETTIS & STROUT
CONSULTING ENGINEERS
Water Supply, Water Treatment,
Sewerage, Sewage Treatment,
Industrial Waste Treatment
2130 Madison Avenue **Toledo 2, Ohio**

FROMHERZ ENGINEERS
Structural - Civil - Municipal
Four Generations Since 1867
Water Supply; Sewerage; Structures; Drainage; Foundations
Industrial Waste Disposal
Investigations; Reports; Plans and Specifications; Supervision
816 Howard Avenue **New Orleans 12, La.**

GANNETT FLEMING CORDDRY & CARPENTER, INC.
ENGINEERS
Dams, Water Works, Sewage, Industrial Wastes & Garbage Disposal, Highways, Bridges & Airports, Traffic & Parking—Appraisals, Investigations & Reports.
HARRISBURG, PENNA.
Branch Offices: Pittsburgh, Pa. Philadelphia, Pa. Daytona Beach, Fla.

GIBBS & HILL, INC.
Consulting Engineers
Industrial and Municipal Waste Treatment
Water Supply and Treatment
Electric Power and Transmission
Transportation and Communication
PENNSYLVANIA STATION
NEW YORK 1, NEW YORK

GILBERT ASSOCIATES, INC.
Engineers and Consultants
Water Supply and Purification
Sewage and Industrial Waste Treatment
Chemical Laboratory Service
Investigations and Reports
P.O. Box 1498
New York **READING, PA.** **Washington**

HOWARD R. GREEN CO.
Consulting Engineers
Established 1913
H. R. GREEN
C. D. MULLINEX G. R. HOTCHKISS
J. A. SAMPSON H. A. MILLER
G. C. AHRENS B. W. GRIFFITH
Water, Sewerage & Industrial Wastes
Public Works & Industrial Projects
Green Engineering Building **Cedar Rapids, Iowa**

GREELEY & HANSEN
Engineers
Water Supply, Water Purification
Flood Control, Drainage, Refuse Disposal
Sewerage, Sewage Treatment
14 East Jackson Boulevard, Chicago 4, Illinois

L. B. GRIFFITH
CONSULTING ENGINEER
Research, Reports and Designs on Sewage and Industrial Waste Treatment.
450 West Broad St. **Falls Church, Va.**

Take advantage of the services of these outstanding consultants!

HASKINS, RIDDLE & SHARP
Consulting Engineers
Water—Sewage & Industrial Wastes—Hydraulics
Reports, Design, Supervision of Construction
Appraisals, Valuations, Rate Studies
1009 Baltimore Ave. Kansas City 5, Mo.

DIRECTORY OF ENGINEERS

HAVENS AND EMERSON
A. A. Burger — H. H. Moseley
J. W. Avery — F. S. Palocsay
E. S. Ordway — G. H. Abplanalp
A. M. Mock — S. H. Sutton
Frank C. Tolles, Consultant
Consulting Engineers
WATER, SEWERAGE, GARBAGE, INDUSTRIAL WASTES, VALUATIONS—LABORATORIES
Leader Bldg. Cleveland 14, O. — Woolworth Bldg. New York 7, N. Y.

HAZEN AND SAWYER
ENGINEERS
RICHARD HAZEN — ALFRED W. SAWYER
H. E. HUDSON, JR.
Water and Sewage Works
Industrial Waste Disposal
Drainage and Flood Control
360 Lexington Ave., New York 17, N. Y.

HENNINGSON, DURHAM & RICHARDSON, INC.
Consulting Engineers and Architects since 1917 for more than 700 cities and towns
Water Works, Light and Power, Sewers, Sewage Treatment, Reports, Flood Control, Appraisals, Drainage, Industrial Works
2962 Harney St. Omaha 2, Nebraska

HORNER & SHIFRIN
Consulting Engineers
E. E. BLOSS — V. C. LISCHER
Airports, Sewerage & Drainage, Hydrology, Sewage Treatment, Industrial Waste Treatment, Water Supply & Treatment, Paving, Structures, Industry Engineering Services
1221 Locust Street St. Louis 3, Mo.

GRIT AND HEAVY SLUDGE REMOVAL
CONCRETE RESTORATION
SEWAGE AND WATER WORKS
HUDSON-RUMSEY CO., INC.
Professional Engineers
1679 Niagara St. Buffalo 7, N. Y.

WILLIAM T. INGRAM
Consulting Engineer
Sanitary and Public Health Engineering
Planning—Design—Research—Water
Sewage—Refuse—Industrial Wastes
Air Pollution Control—Industrial Health
Offices:
East Coast 20 Point Crescent Whitestone 57, N.Y.
West Coast 90 Panoramic Way Walnut Creek, Calif.

The Jennings-Lawrence Co.
Civil and Municipal Engineers
Consultants
Water Supply, Treatment & Distribution
Sewers & Sewage Treatment
Reports—Design—Construction
1392 King Ave. Columbus 12, Ohio

JONES, HENRY & WILLIAMS
Consulting Engineers
Water Works
Sewerage & Treatment
Waste Disposal
2000 West Central Ave. Toledo 6, Ohio

KAIGHIN AND HUGHES
ENGINEERS
INDUSTRIAL WASTES DIVISION
E. B. BESSELIEVRE, MGR.
STUDY - DESIGN - EQUIPMENT - CONSTRUCTION
1080 Atlantic Ave. Toledo 1, Ohio

It pays to secure competent and experienced engineering advice!

DIRECTORY OF ENGINEERS

KENNEDY ENGINEERS
COMPLETE ENGINEERING SERVICE
Investigations, Reports, Design
Supervision of Construction and Operation
Sewerage, Sewage Treatment and
Industrial Waste Disposal
Chemical and Biological Laboratory
604 MISSION ST., SAN FRANCISCO 5
Los Angeles Salt Lake City Tacoma

MORRIS KNOWLES Inc.
Engineers
Water Supply and Purification, Sewerage and Sewage Disposal, Valuations, Laboratory, City Planning.
1312 Park Bldg. Pittsburgh 22, Pa.

KOEBIG AND KOEBIG
Consulting Engineers Since 1910
Investigations, Reports, Designs
Sewerage & Sewage Treatment
Water Supply & Water Treatment
Municipal Engineering
3242 West 8th Street, Los Angeles 5, Calif.

LANNING
Sanitary Engineering Co., Inc.
Consulting Engineers
Water, Sewage, Drainage, and Industrial Wastes
Reports, Designs, Supervision Of Construction and Operation
Chemical & Biological Laboratory
1100 South Broad St. Trenton, N. J.

Lozier Consultants, Inc.
Engineers
Sewerage, Sewage Disposal, Water Supply, Water Purification, Refuse Disposal
10 Gibbs Street Rochester 4, N. Y.

GEORGE B. MEBUS, Inc.
Consulting Engineers
Water Supply Sewage Treatment
Industrial Waste Treatment
BROAD STREET TRUST BUILDING
GLENSIDE, PA.

METCALF & EDDY
Engineers
Water, Sewage, Drainage, Refuse and Industrial Wastes Problems
Laboratory Valuations
Airports
Statler Building
Boston 16

JAMES M. MONTGOMERY
Consulting Engineers, Inc.
Water Supply—Water Purification
Sewerage—Sewage and Waste Treatment
Flood Control—Drainage
Valuations—Rates
Investigations—Design—Operation
535 E. Walnut St. Pasadena, Calif.

Nussbaumer, Clarke & Velzy, Inc.
Consulting Engineers
SEWAGE TREATMENT—WATER SUPPLY
INCINERATION—DRAINAGE
INDUSTRIAL WASTE TREATMENT
APPRAISALS
327 Franklin St., Buffalo, N. Y.
500 Fifth Ave., New York 36, N. Y.

O'BRIEN & GERE
Consulting Engineers
Industrial Waste Treatment
Industrial and Municipal Water Supply
Sewerage and Sewage Treatment
400 East Genesee St. Syracuse 2, New York

PARSONS, BRINCKERHOFF, QUADE & DOUGLAS
Civil and Sanitary Engineers
Water, Sewage, Drainage and Industrial Waste Problems.
Structural — Power — Transportation
165 Broadway New York 6, N.Y.

Take advantage of the services of these outstanding consultants!

DIRECTORY OF ENGINEERS

PIATT & DAVIS AND ASSOCIATES
P. D. DAVIS W. M. PIATT, III
Consulting, Designing, and Supervising Engineers
Water Works, Sanitary Sewers, Water Purification
Sewage Treatment, Streets, Power Plants
Electrical Distribution, Reports and Appraisals
One Eleven Corcoran St. Bldg. Durham, N. C.

MALCOLM PIRNIE ENGINEERS
Malcolm Pirnie — Carl A. Arenander
Ernest W. Whitlock — Malcolm Pirnie, Jr.
Robert D. Mitchell — Alfred C. Leonard
MUNICIPAL AND INDUSTRIAL
Water Supply – Water Treatment
Sewage and Waste Treatment
Drainage – Rates – Refuse Disposal
25 West 43rd Street, New York 36, N. Y.
2910 Grand Central Ave., Tampa 9, Florida

LEE T. PURCELL
Consulting Engineer
Water Supply & Purification; Sewerage & Sewage Disposal; Industrial Wastes; Investigations & Reports; Design; Supervision of Construction & Operation
Analytical Laboratories
36 De Grasse St. Paterson 1, N. J.

REAVES & GREGORY
Consulting Engineers
PAUL C. REAVES
PAUL D. GREGORY
3332 West Seventh Fort Worth 7, Texas

RESOURCES RESEARCH, INC.
Municipal and Industrial Air Pollution Control,
Water Supply, Sewage Disposal, Public Health
Reports, Investigations, Research
LOUIS C. MCCABE, *Pres.*
1246 Taylor St., N. W. Washington 11, D. C.

THOMAS M. RIDDICK
Consulting Engineers and Chemists
Municipal and Industrial Water Purification,
Sewage Treatment Plant Supervision,
Industrial Waste Treatment
Laboratories for Chemical and Bacteriological Analyses
369 E. 149th St. New York 55, N.Y.

RIPPLE AND HOWE, Inc.
Consulting Engineers
O. J. RIPPLE V. A. VASEEN B. V. HOWE
Appraisals—Reports
Design—Supervision
Water Works Systems, Filtration and Softening Plants, Reservoirs and Dams, Sanitary and Storm Sewers, Sewage Treatment Plants, Refuse Disposal, Airports
833-35 Twenty-Third St. Denver 5, Colorado

ROBERT AND COMPANY ASSOCIATES
ARCHITECTS AND ENGINEERS
ATLANTA

RUSSELL AND AXON
Consulting Engineers
Civil — Sanitary — Structural
Industrial — Electrical
Rate Investigations
408 Olive St., St. Louis 2, Mo.
Municipal Airport, Daytona Beach, Fla.

SERVIS, VAN DOREN & HAZARD
Engineers-Architects
Investigations · Design · Supervision of Construction · Appraisals
Water · Sewage · Streets · Expressways · Highways
Bridges · Foundations · Airports · Flood Control
Drainage · Aerial Surveys · Site Planning · Urban
Subdivisions · Industrial Facilities · Electrical
Mechanical
2910 Topeka Blvd. Topeka, Kansas

J. E. SIRRINE COMPANY
Engineers Since 1902
GREENVILLE, SOUTH CAROLINA
Design, Reports, Consultations
Water Supply and Treatment
Sewage and Industrial Waste Treatment
Stream Pollution Surveys
Chemical and Bacteriological Analyses

It pays to secure competent and experienced engineering advice!

DIRECTORY OF ENGINEERS

SMITH and GILLESPIE
Consulting Engineers
All types of
Municipal Public Works &
Utilities
Complete Services
P. O. Box 1048, Jacksonville, Fla.

STANLEY ENGINEERING COMPANY
Consulting Engineers
Hershey Building **208 S. LaSalle Street**
Muscatine, Iowa **Chicago 4, Illinois**
1154 Hanna Building
Cleveland 15, Ohio

ALDEN E. STILSON & ASSOCIATES
Limited
Consulting Engineers
Water Supply—Sewerage—Waste Disposal
Bridges—Highways—Industrial Buildings
Studies—Surveys—Reports
245 N. High St. **Columbus 15, Ohio**

TIGHE & BOND
CONSULTING ENGINEERS
Bowers and Pequot Streets
Holyoke, Massachusetts
Tel. JEfferson 3-3991
Civil, Sanitary and Electrical Engineering
Investigations, Reports, Plans and Specifications
Supervision of Construction and Operation

WALLACE & HOLLAND
Consulting Engineers
Civil — Sanitary — Structural
401 N. Federal **Mason City, Iowa**

J. STEPHEN WATKINS
J. S. WATKINS G. R. WATKINS
CONSULTING ENGINEERS
Municipal and Industrial Engineering, Water Supply and Purification, Sewerage and Sewage Treatment, Highways and Structures, Reports, Investigations and Rate Structures.
446 East High Street **Lexington, Kentucky**
Branch Office
4726 Preston Highway **Louisville, Kentucky**

ROY F. WESTON, INC.
Engineers—Biologists—Chemists
Industrial Wastes
Stream Pollution—Air Pollution
Water—Sewage
Surveys—Research—Development—Process Engineering — Plans and Specifications — Operation Supervision — Analyses — Evaluations and Reports
Newtown Square **Pennsylvania**

WESTON & SAMPSON
Consulting Engineers
Water Supply Water Purification
Corrosion Control
Sewerage, Sewage and Industrial Wastes Treatment
Stream Pollution Studies
Supervision, Valuation
Laboratory
14 Beacon Street **Boston 8, Mass.**

WHITMAN & HOWARD
Engineers (Est. 1869)
Sewerage, Sewage Disposal, Municipal and Industrial Development Problems, Water Supply, Water Purification, Water Front Improvements, Investigations, Reports, Designs, Supervision, Valuations
89 Broad Street, Boston, Mass.

WHITMAN, REQUARDT & ASSOCIATES
Engineers—Consultants
Civil — Sanitary — Structural
Mechanical — Electrical
Reports, Plans, Supervision, Appraisals
1304 St. Paul Street **Baltimore 2, Maryland**

WILSON & COMPANY
ENGINEERS & ARCHITECTS
Investigations — Planning — Design
Water, Sewerage, Streets, Highways, Bridges, Electrical, Airfields, Drainage, Dams, Treatment Plants, Industrial Installations
Chemical Testing Lab — Aerial Mapping
Electronic Computer Services, Reproductions
631 East Crawford - - Salina, Kansas
2930 Geo. Washington Ave., Wichita, Kansas

Take advantage of the services of these outstanding consultants!

INDEX TO ADVERTISERS

(See pages 360a, 362a, 364a, and 366a for full listing of products.)

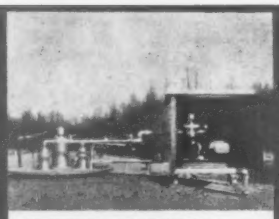
	Page
Amercoat Corporation	355a
American Brass Company	342a
American-Marietta Company	329a
American Well Works	350a
Armco Drainage and Metal Products, Incorporated	357a
B-I-F Industries, Incorporated	Inside Front Cover
Cast Iron Pipe Research Association	338a, 339a
Chain Belt Company	345a
Chicago Pump Company	317a
Dorr-Oliver Incorporated	348a
Eimco Corporation	326a, 327a
Fischer and Porter Company	328a
Flexible Incorporated	330a
General Chemical Division (Allied Chemical Corporation)	343a
Glenn Chemical Company	363a
Hardinge Company, Incorporated	346a
Infilco Incorporated	331a
Jeffrey Manufacturing Company	358a
Johns-Manville Sales Corporation	341a
Keasbey and Mattison Company	332a, 333a
Lakeside Engineering Corporation	336a
Link-Belt Company	354a
Lock Joint Pipe Company	Inside Back Cover
National Clay Pipe Manufacturers, Incorporated	337a
Nichols Engineering and Research Corporation	321a
Ohmart Corporation	351a
Pacific Flush Tank Company	319a
Pfaudler Permutit Incorporated	334a
Robinson Clay Product Company	353a
Snow Gates and Valves	365a
Sonoco Products Company	335a
Stebbins Engineering and Manufacturing Company	344a
Stewart, W. H., Incorporated	359a
Tex-Vit Supply Company	323a
Trickling Filter Floor Institute	347a
Vapor Recovery Systems Company	349a
Walker Process Equipment Incorporated	378a
Wallace and Tiernan Incorporated	Back Cover
Webster Manufacturing, Incorporated	352a
Yeomans Brothers Company	340a
Zimmer and Francescon	367a

DIRECTORY OF ENGINEERS, 369a–376a

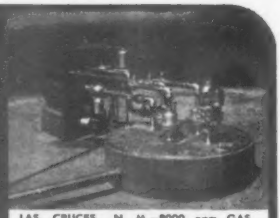
Albright and Friel, Inc.
Alvord, Burdick & Howson
Anderson-Nichols & Company
Baffa, John J.
Baker, Michael, Jr., Inc.
Baxter and Woodman
Beak, Thomas W.
Bell, Howard K.
Betz Laboratories, Inc.
Black & Veatch
Bogert, Clinton, Engineers
Bowe, Albertson & Associates
Boyle Engineering
Brown & Caldwell
Brown Engineering Co.
Browne, Floyd G., and Associates
Buck, Seifert & Jost
Burgess & Niple
Burns & McDonnell
Camp, Dresser and McKee
Capitol Engineering Corp.
Chester Engineers, The
Consoer, Townsend & Associates
Everson, Roy B.
Fay, Spofford & Thorndike, Inc.
Finkbeiner, Pettis & Strout
Fromherz Engineers
Gannett Fleming Corddry & Carpenter, Inc.
Gibbs & Hill, Inc.
Gilbert Associates, Inc.
Greeley & Hansen
Green, Howard R., Co.
Griffith, L. B.
Haskins, Riddle & Sharp
Havens and Emerson
Hazen and Sawyer
Henningson, Durham & Richardson, Inc.
Horner & Shifrin
Hudson-Rumsey Co., Inc.
Ingram, William T.
Jennings-Lawrence Co.
Jones, Henry & Williams
Kaighin and Hughes
Kennedy Engineers
Knowles, Morris, Inc.
Koebig & Koebig
Lanning Sanitary Engineering Co., Inc.
Lozier Consultants, Inc.
Mebus, George B., Inc.
Metcalf & Eddy
Montgomery, James M.
Nussbaumer, Clarke & Velzy, Inc.
O'Brien & Gere
Parsons, Brinckerhoff, Quade & Douglas
Piatt & Davis and Associates
Pirnie, Malcolm, Engineers
Purcell, Lee T.
Reaves & Gregory
Resources Research, Inc.
Riddick, Thomas M.
Ripple and Howe, Inc.
Robert and Company Associates
Russell and Axon
Servis, Van Doren & Hazard
Sirrine, J. E., Co.
Smith and Gillespie
Stanley Engineering Company
Stilson, Alden E., & Associates
Tighe & Bond
Wallace & Holland
Watkins, J. Stephen
Weston, Roy F., Inc.
Weston & Sampson
Whitman & Howard
Whitman, Requardt & Associates
Wilson & Company

PATRONIZE OUR ADVERTISERS—whose support makes possible the publication of this journal. *When writing advertisers be sure to mention JOURNAL of the WATER POLLUTION CONTROL FEDERATION.*

ROCKFORD, ILL.—Three GASLIFTERS in existing digesters. Henry Riedesel, Mgr., San. Dist. Greeley and Hansen, Chicago, Cons. Engrs.



GREENSBORO, N. C.—GASLIFTER in existing 75' dia. digester with floating cover. Don Holder, Supt. City of Greensboro, Engrs.

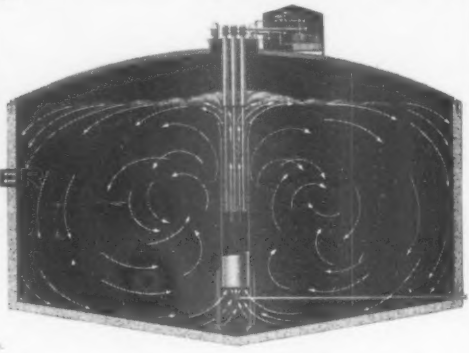


LAS CRUCES, N. M.—8000 gpm GASLIFTER in 50' dia. digester with fixed cover. R. A. Smith, Supt. Gordon Herkenhoff & Assoc., Albuquerque, Cons. Engrs.

GASLIFTER

DIGESTER CIRCULATOR - MIXE

GASLIFTER is a trademark of Walker Process Equipment Inc.



GASLIFTERS incorporate the patent right of Joseph Cunetta.

NO INACTIVE ZONES—permits utilization of entire digester capacity allowing higher loading rate.
IMPROVES OPERATION—circulates and mixes digester contents and insures uniform distribution of raw and seeded sludge.
CONTROLS START-UP—avoids start-up troubles by completely homogenizing contents; induces rapid gasification and volatile acids remain low.
ELIMINATES SCUM BLANKET AND GRIT SHOALS—circulation velocity at roof, sides and floor disperses grease blanket and bottom shoals.
EASY INSPECTION—exclusive locking chamber permits individual inspection and servicing of GASLIFTER sparging units without dangerous gas loss or digester shutdown. Eductor Tube, Gas-Lift principle avoids mechanical troubles from rag and "sewage string" fouling.

SACRAMENTO COUNTY, CALIF. (San. Dist. #3) GASLIFTER in 70' dia. digester with fixed concrete cover. Mr. Norman Farnum, Supt. Dewante & Stowell, Sacramento, Cons. Engrs.

SALT LAKE COUNTY, UTAH—(Suburban San. Dist.)—12,000 gpm GASLIFTER in 60' dia. digester. Emil Meyers, Supt. Caldwell, Richards & Sorenson, Inc., Salt Lake City, Cons. Engrs.

AURORA, ILL.—10,000 gpm GASLIFTER in existing 50' sq. digester. Willard P. Pfeiffer, Supt. W. E. Dauchler, Assoc., Inc., Aurora, Cons. Engrs.

WALKER PROCESS

WALKER PROCESS EQUIPMENT INC.
FACTORY • ENGINEERING OFFICES • LABORATORIES
AURORA, ILLINOIS

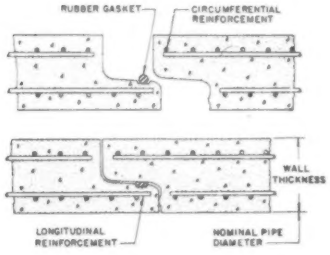
For the utmost in

DURABILITY . . . RELIABILITY . . . FLEXIBILITY . . .

LOCK JOINT CONCRETE ROLLER SUSPENSION PIPE with the RUBBER and CONCRETE JOINT

LOCK JOINT

RUBBER and CONCRETE JOINT



SEWER AND CULVERT PIPE PLANTS:

Kenilworth, N. J.	Beloit, Wis.	Denver, Colo.
Hartford, Conn.	Chicago, Ill.	Cheyenne, Wyo.
New Haven, Conn.	Rock Island, Ill.	Casper, Wyo.
Buffalo, N. Y.	Valley Park, Mo.	Tucumcari, N. Mex.
Rochester, N. Y.	N. Kansas City, Kans.	Hato Rey, Puerto Rico
Edgewater, Fla.	Tulsa, Okla.	Carolina, Puerto Rico
Miami, Fla.	Oklahoma City, Okla.	Ponce, Puerta Rico
W. Palm Beach, Fla.	Wichita, Kans.	Caracas, Venezuela

Long life is built into every section of Lock Joint Roller Suspension Sewer and Culvert Pipe through a manufacturing process which produces concrete walls of unusual strength and density.

The non-corrosive, non-tuberculant inner surface of the pipe is remarkably resistant to abrasion and assures continued high flow characteristics and trouble-free service.

Lock Joint's Rubber and Concrete Joint, available in this type of pipe and in some designs of conventionally cast pipe, gives maximum protection against infiltration while affording ample flexibility to accommodate deflections due to ground settlement and expansion of contraction due to temperature changes.

For economy in jointing, Roller Suspension Pipe is produced in standard 8′ lengths and is available in diameters from 12″ to 72″. Lock Joint Pipe Company also produces machine made and cast pipe ranging in diameter from 6″ to 120″ or even larger if required. All Lock Joint sewer and culvert pipe may be designed to comply with A.S.T.M., State Highway or individual specifications.

LOCK JOINT PIPE CO.

East Orange, New Jersey

Pressure • Water • Sewer • **REINFORCED CONCRETE PIPE** • Culvert • Subaqueous

W&T **RESIDUAL CHLORINATION SYSTEMS**

Automatic residual recording by Wallace & Tiernan gives you a finger on the pulse of your chlorination operation. Your system's performance is analyzed; the results recorded accurately. You have an eye on water quality.

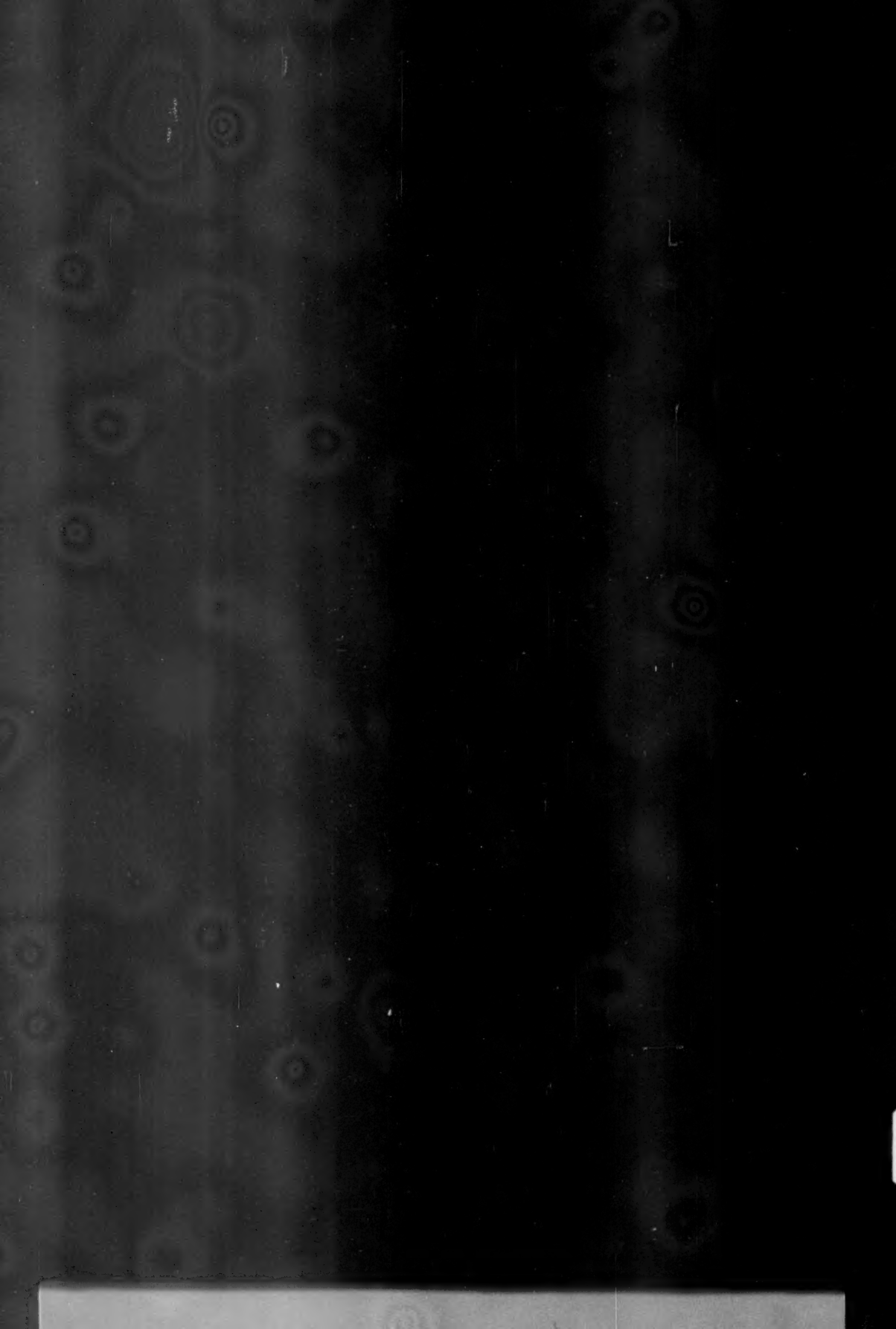
Accurate minute-to-minute records guide plant operation . . . furnish proof of your water's safety. You can analyze your operation and work out efficient maintenance and supervisory routines.

And a W&T Automatic Residual System opens the door to complete automation. You have the basis for Compound-loop Control, the ultimate in chlorination automation.

You can build Compound-loop Control component by component. As the future demands, you can add W&T auxiliary equipment to achieve this closed-loop, information-feedback system, no matter what your present arrangement.

For more information, write Dept. S-140.84

WALLACE & TIERNAN INCORPORATED

25 MAIN STREET BELLEVILLE 9, NEW JERSEY

LANCASTER PRESS, INC., LANCASTER, PA.